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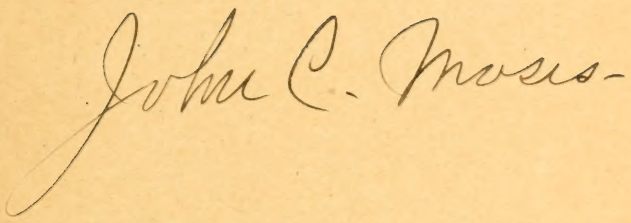

TRANSACTIONS

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AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XXXIII.

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Vol. XXXIII.—January, 1895.

THE HALSTED STREET LIFT-BRIDGE.

By J. A. L. WADDELL, M. Am. Soc. C. E.

READ NOVEMBER 7TH, 1894.

WITH DISCUSSION.

History.—For a number of years there was a rotating combination draw bridge over the South Branch of the Chicago River at Halsted Street, but on June 30th, 1892, a vessel ran into it and knocked it down. When the city attempted to rebuild it, the lake navigation interests objected to having another rotating draw span at this crossing, on the plea that the pivot pier of the old bridge was always a serious obstruction to navigation; and they used such influence with the War Department that the city was restrained from building the structure as contemplated. The Commissioner of Public Works of Chicago at that time was the Hon. J. Frank Aldrich, who a few months later was elected to Congress. Mr. Aldrich was placed in a rather awkward predicament, for, on the one hand, the people of the district in the neighborhood of the Halsted Street crossing—which, by the way, is one of the greatest thoroughfares of the city—were clamoring for a bridge; and, on the other hand, the United States Engineer Corps would not permit him to build any structure which would narrow the water-way to any such extent as would a rotating draw span.

The folding bridge or "jack-knife draw" design, one of which pattern was then under construction at another crossing of the Chicago River, was advocated by certain parties; but Mr. Aldrich, who is himself, or, perhaps, more strictly speaking, was, a civil engineer, did not consider this type of bridge sufficiently rigid for the long span and for the heavy traffic.

After making a thorough study of the problem, Mr. Aldrich decided upon building a lift-bridge similar to the one designed previously by the writer for the proposed crossing of the ship canal at Duluth; and after considerable delay, permission was obtained from the War Department to build the structure, with the proviso, however, that the clear headway be increased from 140 to 155 ft. above mean low water.

Before the demand for extra clear height was made, bids had been asked for, and the contract had been awarded provisionally, on schedule prices for materials in place, to the Pittsburgh Bridge Company (W. W. Curtis, M. Am. Soc. C. E., Engineer), with the Hale Elevator Company of Chicago as subcontractors for the machinery, which latter company afterwards transferred its contract to the Crane Elevator Company of the same city. But it was not until the beginning of 1893 that the contract for building the bridge was finally signed, sealed and delivered. Even then the tribulations of those interested in the enterprise were not at an end, for the letting of the contract was irregular, in that there was no money in the City Treasury to pay for the bridge; so, according to the usual custom for such conditions, reliance was placed on the Finance Committee and Board of Aldermen voting, later on, the necessary funds. Under ordinary circumstances this irregularity would have done no harm; but in this case it was otherwise, because it gave each Alderman and each city official an opportunity to tie up the work if he so desired, by alleging that the scheme was impracticable and that the bridge could not possibly work successfully. Continual worry was experienced on this account, and it is fair to say that to this circumstance is mainly due the great delay in completing the contract, which required fifteen months, instead of the six months allowed. In fact, it was at one time doubtful whether the subcontractors for the machinery would ever finish their work because they debated seriously whether it would not be better to lose about $15 000, which they had already put in, rather than risk completing the contract and never receiving a dollar in pay-

PLATE I.
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WADDELL ON HALSTED STREET LIFT-BRIDGE.

ment. This difficulty, however, was tided over by Mr. Curtis, who gave to his subcontractors such satisfactory assurances that they would be paid eventually that they decided to proceed with their work.

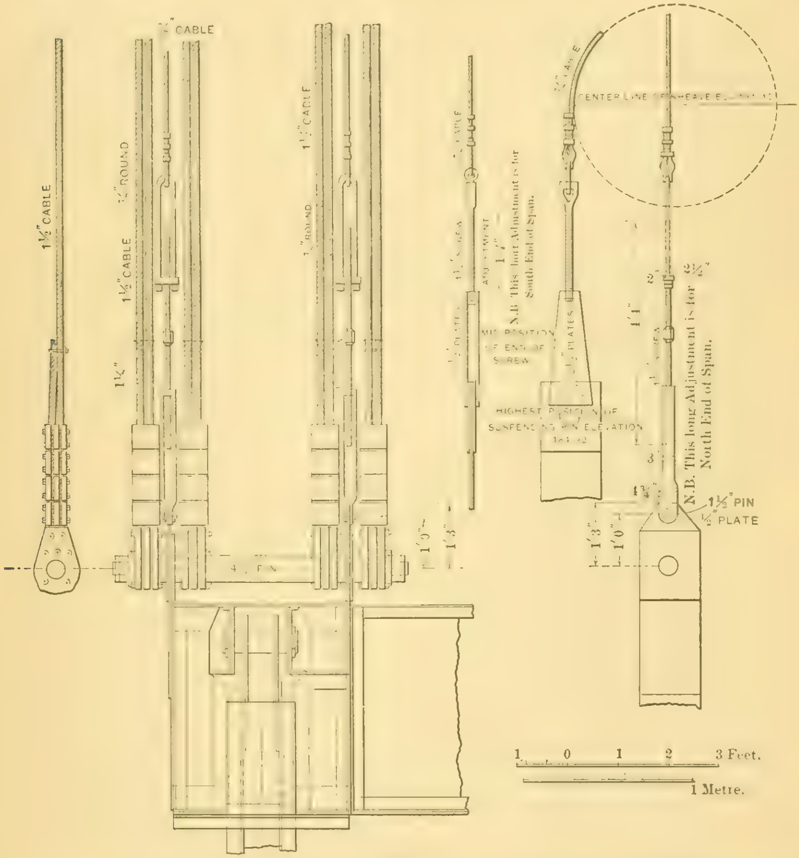
Another main cause of difficulty and delay was the continual changing of city officials, for in the two years during which this bridge subject was on the *tapis* there were three changes of administration, involving the election or appointment of three Mayors, three Commissioners of Public Works, and three City Engineers, to say nothing of minor officials.

General Description.—The location of this bridge is a very awkward one, for not only does Halsted Street cross the river on a skew of $10\frac{1}{2}^\circ$, but there is an offset in it of $41\frac{1}{2}$ ft. just at the crossing. This combination involves a skew of $22\frac{1}{2}^\circ$ for the structure in respect to the channel. By setting the main and rear piers on lines at right angles to the central plane of structure, the effect of the skew was taken out of the bridge and carried to the machinery house and the street retaining walls.

As shown on Plates I, II, the bridge consists of a single Pratt truss, through span of 130 ft., in seven equal panels, and having a truss depth of 23 ft. between centers of chord pins, so supported and constructed as to permit of being lifted vertically to a height of 155 ft. clear above mean low water. At its lowest position the clearance is about 15 ft., which is sufficient for the passage of tugs when their smokestacks are lowered. The span differs from ordinary bridges only in having provisions for attaching the sustaining and hoisting cables, guide rollers, etc., and in the inclination of the end posts, which are battered slightly, so as to bring their upper ends at the proper distance from the tower columns, and their lower ends in the required positions on the piers.

At each side of the river is a strong, thoroughly braced, steel tower, about 217 ft. high from the water to the top of the housing, exclusive of the flag poles, carrying at its top four built-up steel and cast-iron sheaves, 12 ft. in diameter, which turn on 12-in. axles. Over these sheaves pass the $1\frac{1}{2}$-in. steel wire ropes (32 in all) which sustain the span. These ropes are double, *i. e.*, two of them are brought together where the span is suspended, and the ends are fastened by clamps, as shown in Fig. 1; while, where they attach to the counterweights,

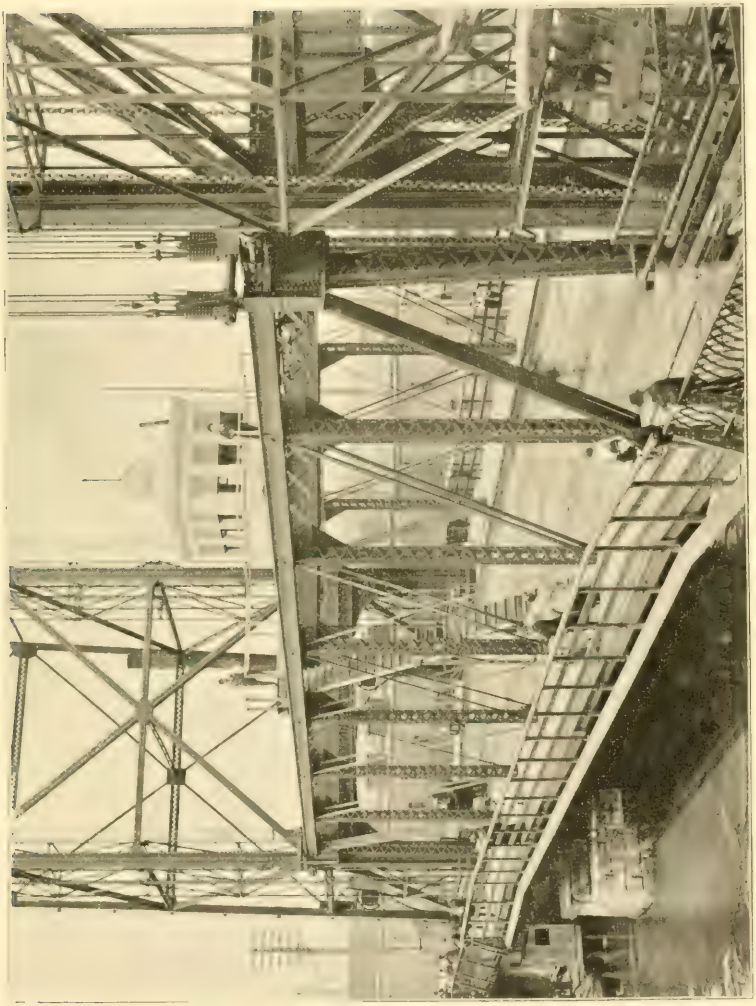
they form a loop, which passes around a 15-in. wheel or pulley that acts as an equalizer in case the two adjacent ropes tend to stretch unequally.



DETAILS OF ATTACHMENTS OF CABLES TO SPAN.
FIG. 1.

The counterweights, which are intended to just balance the weight of the span, consist of a number of horizontal cast-iron blocks about 10 x 12 ins., in section, and 8 ft. 7 ins. long, strung on adjustable wrought-iron rods that are attached to the ends of rockers, at the middle of each of which is inserted the 15-in. equalizing wheel or pulley previously mentioned.

The counterweights run up and down in guide frames built of 3-in. angles, as shown on Plate III.



The weight of the cables is counterbalanced by that of wrought-iron chains, one end of each chain being attached to the span, and the other end to the counterweights, so that, whatever may be the elevation of the span, there will always be the same combined weight of sustaining cables and chain on one side of each main sheave as there is upon its other side.

Between the tops of the opposite towers pass two shallow girders thoroughly sway-braced to each other, and riveted rigidly to said towers. The main function of these girders is to hold the tops of the towers in correct position; but incidentally they serve to support the idlers of the operating ropes and to afford a footwalk from tower to tower for the use of the bridge tender. Adjustable pedestals under the rear legs of each tower provide for unequal settlement of the piers which support the tower columns. Each of these pedestals, as shown on Plate IV, has an octagonal forged steel shaft, expanding into a sphere at one end, and into a cylinder with screw threads at the other. The ball end works in a spherical socket on a pedestal, and the screw end works in a female screw in a casting, which is very firmly attached to the bottom of the tower leg. By turning the octagonal shaft, it is evident that the rear column will be lengthened or shortened. The turning is accomplished by means of a special bar of great strength, which fits closely to the octagon at one end, and to the other end of which can be connected a block and tackle, if necessary. These screw adjustments were useful in erecting the structure, but it is quite likely that they will never again be needed. But in case there is ever any tower adjustment required, it will be found that the extra money spent on them will have been well expended.

Some persons have questioned the ability of these screws to work after they have stood for some length of time; but as the rear columns carry only a small portion of the weight of the tower and occasionally some wind pressure, no great difficulty is anticipated in making adjustments, should any ever be required.

Moreover, as the main piers rest on bedrock, while the rear piers are on grillages and piles, it stands to reason that any deviation from adjustment would be due to a settlement of the rear piers and a consequent loosening of the rear pedestals, which would relieve the load on the screws, and thus reduce the frictional resistance to turning. Provision is to be made for oiling the screws, by drilling holes into the

castings and attaching oil cups thereto. This matter was overlooked in making the design. In case the main piers had not gone down to rock, the omission might have given trouble; but, as it is, it could not have done so.

Each tower consists of two vertical legs against which the roller guides on the trusses bear, and two inclined rear legs. These legs are thoroughly braced together on all four faces of the tower; and at each tier thereof there is a system of horizontal sway bracing, which will prevent most effectively every tendency to distort the tower by torsion.

At the tops of the towers there are four hydraulic buffers that are capable of bringing the span to rest without jar from its greatest velocity, which was assumed to be 4 ft. per second; and there are four more of these buffers attached beneath the span, one at each corner, to serve the same purpose.

The span, with all that it carries, weighs about 290 tons, and the counterweights weigh, as nearly as may be, the same. As the cables and their counterbalancing chains weigh fully 20 tons, the total weight of the moving mass is almost exactly 600 tons.

Should the span and counterweights become out of balance on account of a greater or less amount of moisture, snow, dirt, etc., in and on the pavement and sidewalks, it can be adjusted by letting water into and out of ballast tanks located beneath the floor; and should this adjustment be insufficient, provision is made for adding small weights to the counterweights, or for placing such weights on the span.

As the counterweights thus balance the weight of the span, all the work which the machinery has to do is to overcome the friction, bend the wire ropes, and raise or lower any small unbalanced load that there may be. It has been designed, however, to lift a considerable load of passengers in case of necessity, although the structure is not intended for this purpose, and should never be so used to any great extent.

The span is steadied while in motion by rollers at the tops and bottoms of the trusses, as shown on Plate II. There are both transverse and longitudinal rollers, the former not touching the columns, unless there is sufficient wind pressure to bring them to a bearing. The longitudinal rollers, though, are attached to springs, which press them against the columns at all times, and take up the expansion and contraction of the trusses. With the rollers removed, the bridge swings

PLATE III.
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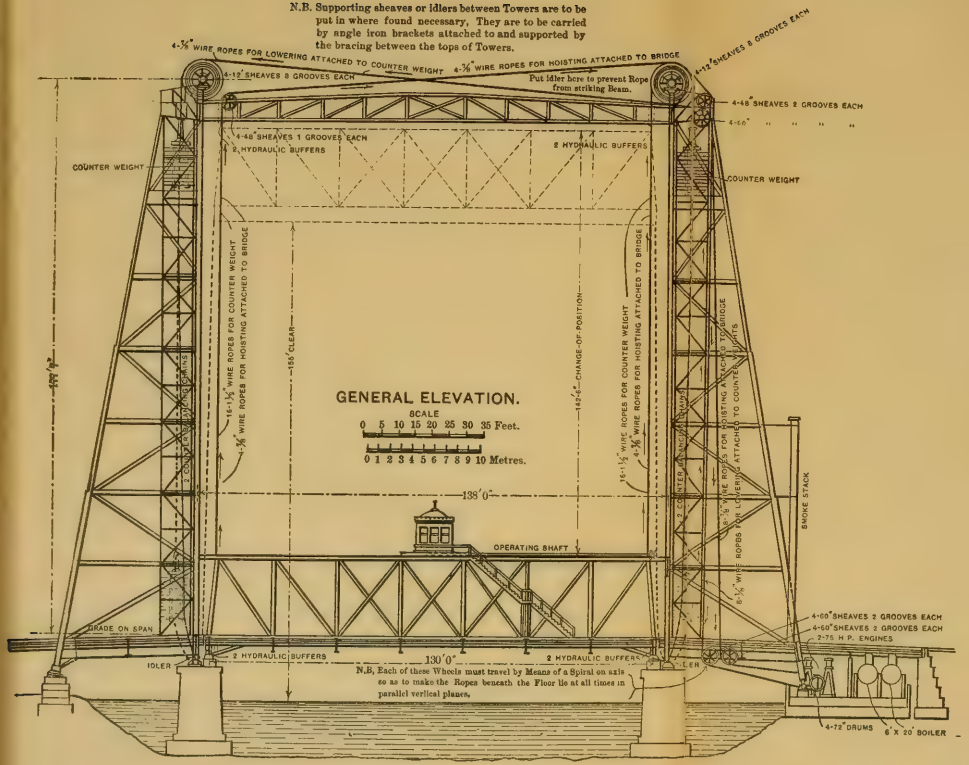
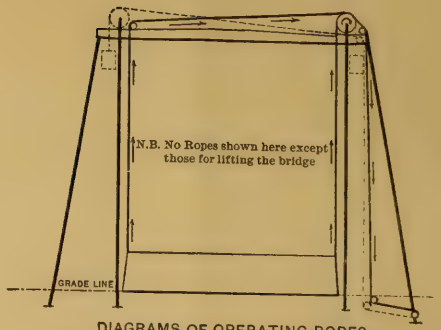
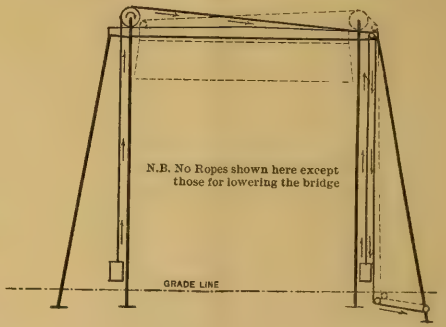
WADDELL ON HALSTED STREET LIFT-BRIDGE.


N.B. Supporting sheaves or idlers between Towers are to be put in where found necessary, They are to be carried by angle iron brackets attached to and supported by the bracing between the tops of Towers.
4-⅞" WIRE ROPES FOR LOWERING ATTACHED TO COUNTER WEIGHT
4-⅞" WIRE ROPES FOR HOISTING ATTACHED TO BRIDGE
4-12' SHEAVES 8 GROOVES EACH
Put Idler here to prevent Rope from striking Beam.
4-12' SHEAVES 8 GROOVES EACH
4-48" SHEAVES 2 GROOVES EACH
4-60" " " " "
4-48" SHEAVES 1 GROOVES EACH
2 HYDRAULIC BUFFERS
2 HYDRAULIC BUFFERS
COUNTER WEIGHT
COUNTER WEIGHT
16-1½" WIRE ROPES FOR COUNTER WEIGHT
⅞" WIRE ROPES FOR HOISTING ATTACHED TO BRIDGE
155' CLEAR
142'4" CHANGE-OF-POSITION
16-1½" WIRE ROPES FOR COUNTER WEIGHT
4-⅞" WIRE ROPES FOR HOISTING ATTACHED TO BRIDGE
4-⅞" WIRE ROPES FOR LOWERING ATTACHED TO COUNTER WEIGHTS
GENERAL ELEVATION.
SCALE
0 5 10 15 20 25 30 35 Feet.
0 1 2 3 4 5 6 7 8 9 10 Metres.
138'0"
OPERATING SHAFT
SMOKE STACK
BRADE ON SPAN
IDLER
2 HYDRAULIC BUFFERS
130'0"
2 HYDRAULIC BUFFERS
IDLER
N.B. Each of these Wheels must travel by Means of a Spiral on axis so as to make the Ropes beneath the Floor lie at all times in parallel vertical planes.
4-60" SHEAVES 2 GROOVES EACH
4-60" SHEAVES 2 GROOVES EACH
2-75 H.P. ENGINES
4-72" DRUMS
6 X 20' BOILER



DIAGRAMS OF OPERATING ROPES.



free of the columns; and, since the attachments are purposely made weak, the result of a vessel's striking the bridge with its hull will be to tear them away and swing the span to one side. Should the rigging of the vessel, however, strike the span, the effect will be simply to break off the masts without injury to the bridge. This latter accident has happened once already, the result being exactly what the writer had predicted. There is a special apparatus, consisting of a heavy square timber set on edge, trimmed on the rear to fit into a steel channel which rivets to the cantilever brackets of the sidewalk, and faced with a 6 x 6-in. heavy angle iron, to act as a cutting edge. This detail, which is a very effective one for destroying the masts and rigging of colliding vessels, is shown in the photograph of the structure reproduced on Plate II. The adoption of a wooden handrail on the span, while a steel one is used on the rest of the bridge, is a wise precaution against expense caused by collisions. The wooden rail is easily replaced by any carpenter, and is quite cheap; while the steel rail, if broken or bent, as it is liable to be, would be not only costly, but also difficult to match in replacing, and comparatively expensive to repair. Of course, the wooden rail is not quite so sightly as the metal one. The writer had contemplated using the latter over the entire structure, and conceded the change to a wooden rail with some reluctance, but is now convinced that it is the proper thing for the place. This wooden rail and the exterior guard are standard devices of the City Engineer's office of Chicago.

The bridge is designed to carry a double-track street railway, vehicles and foot passengers, as can be seen by the photographic view shown on Plate II. It has a clear roadway of 34 ft. between the counterweight guides in the towers, the narrowest part of the structure, and two cantilevered sidewalks, each 7 ft. in the clear, the distance between central planes of trusses being 40 ft., and the extreme width of suspended span 57 ft., except at the end panels, where it is increased gradually to 63 ft. The roadway, as shown in Fig. 2, is covered with a wooden block pavement 34 ft. wide between guard rails resting on a 4-in. pine floor that in turn is supported by wooden shims, which are bolted to 15-in. I-beam stringers spaced about 3 ft. 3 ins. from center to center. These stringers rivet up to the webs of the floor beams; and beneath them run diagonal angles, which rivet to the bottom flange of each stringer, and thus form a very efficient lower

lateral system. The sidewalks are covered with 2-in. pine planks, resting on 3 x 12-in. pine joists spaced about 2 ft. from center to center.

The span is suspended at each of the four upper corners of the

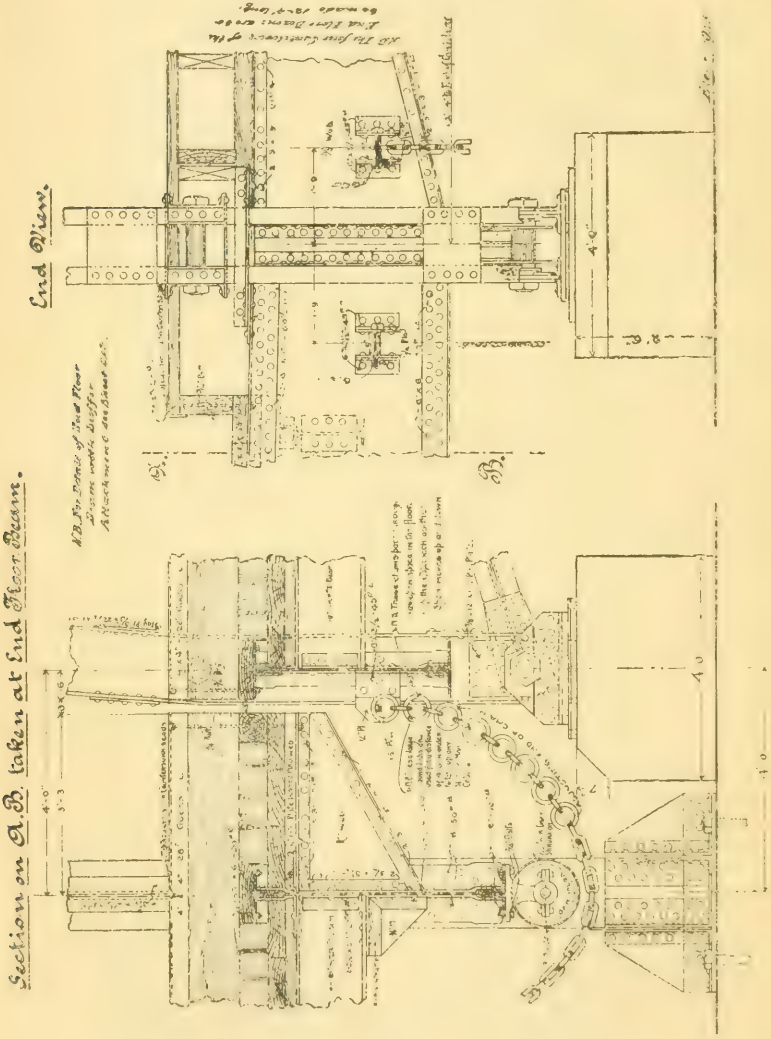


FIG 2.

trusses by eight steel cables, which take hold of a pin by means of cast-steel clamps. This pin passes through two hanger plates, which project above the truss, and are riveted very effectively to the end

SECTION AND PART ELEVATION OF BUFFER.

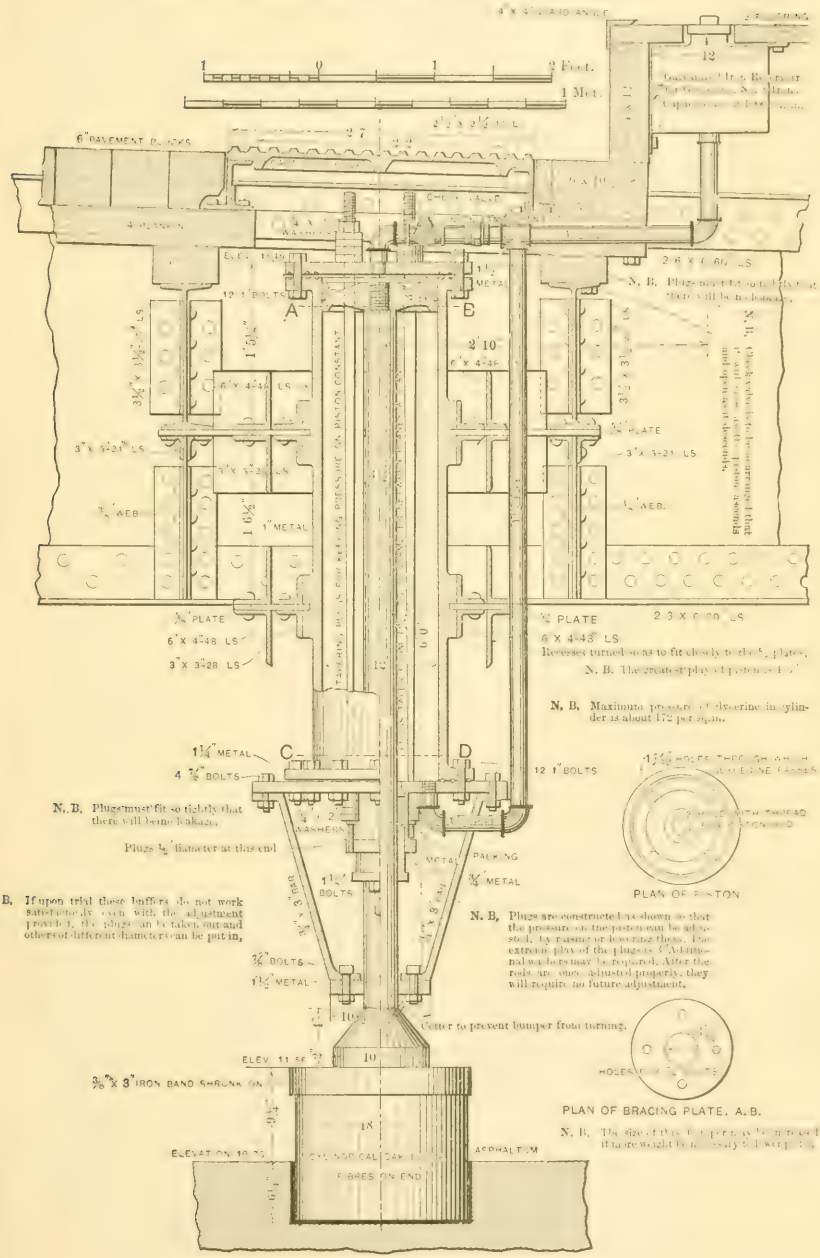

1 0 1 2 Feet.
1 Met.
6" PAVEMENT BLOCKS
12 1" BOLTS
A
B
C
D
1¼" METAL
4 ⅞" BOLTS
N. B. Plugs must fit so tightly that there will be no leakage.
Plugs ½" diameter at this end
N. B. If upon trial these buffers do not work satisfactorily even with the adjustment provided, the plugs can be taken out and others of different diameters can be put in.
⅞" BOLTS
1¼" METAL
Cutter to prevent bumper from turning.
⅜" X 3" IRON BAND SHRUNK ON
ELEVATION OF PISTON
CYLINDRICAL OAK FIBRES ON END
ASPHALTUM
N. B. Maximum pressure of glycerine in cylinder is about 172 per sq. in.
N. B. Plugs are constructed as shown so that the pressure on the piston can be adjusted, by raising or lowering them. The external plan of the plugs is additional when they are adjusted properly, they will require no future adjustment.
PLAN OF PISTON
PLAN OF BRACING PLATE, A, B.
N. B. The size of this buffer is given for a bridge weighing 1,000 tons.

FIG. 3.

post by means of the portal plate girder strut on the inside and a special short cantilever girder on the outside, as shown in Fig. 1.

Each portal girder carries near each end an iron-bound oak block to take up the blow from the hydraulic buffer, which hangs from the overhead girder between towers. Similar oak blocks are let into and project from the copings of the main piers, as shown in Fig. 3, to take up the blow from the hydraulic buffers that are attached to the span.

The ballast tanks before alluded to, of which there are four in all, are built of steel plates properly stiffened, and have a capacity of about 19 000 lbs., which is probably more than enough to set the bridge in motion if it were all an unbalanced load. These tanks serve a double purpose, the first being simply to balance the bridge when it gets out of adjustment because of the varying load of moisture, etc., on the span, and the second being to provide a quick and efficient means of raising and lowering the span in case of a total breakdown of the machinery. If, for instance, which is highly improbable, the operating ropes were broken and had to be detached from their drums, by emptying all of the water out of the tanks, the span could be made to rise. It could be lowered again by filling them from a reservoir which is placed on top of one of the towers and kept filled with water at all times by means of a pump in the machinery house. The water in all of these tanks can be kept from freezing, or the ice therein can be thawed at any time by turning on steam from the machinery room into the coils of pipe which they contain.

Although the necessity for using the tanks for operating the bridge will probably never arise, nevertheless some experiments ought to be made, to ascertain what weight of water is required to unbalance the bridge sufficiently to put it in motion. In operating the bridge by the water ballast it would be necessary to take the precaution to place a simple, temporary friction brake of some kind at each corner of the span to press against the column, and thus prevent the attainment of too great a velocity. A stick of timber could be made to answer this purpose. It would do as well to apply these brakes to the main sheaves. All four tanks are connected by pipes so that the water in them can be kept at the same level; and these pipes are provided with stop cocks so that they can be drained in winter, to prevent their contents from freezing and bursting them, or so that any one tank can be

emptied without discharging the others. Should the water in the tanks freeze, it would do no harm, because the sides thereof are battered. Access is had to the tanks by means of manholes through the paved floor, which holes are covered with cast-iron plates, properly ribbed, to give good foothold for horses.

On the floor at the entrances to the towers and at the corners of the counterweight guides are placed curved cast-iron bumpers, to protect the rear columns and the said guides from being injured by passing vehicles.

The lower ends of the counterweight frames are fenced in with wire netting, to prevent persons from injury by the descending counterweights.

It would be well to adopt automatic gates at each end of the bridge to shut off traffic from both roadway and footwalks when the bridge is being operated or just about to be. As such devices are not employed on the other Chicago bridges, at least not to any great extent, the writer did not provide for them in his design, preferring to leave the matter to the City Engineer's office. At present, traffic is stopped by a policeman, who stretches a rope across the roadway in the north tower; but there is nothing to prevent foot passengers from crowding out to the open ends of the footwalks, where there exists the double danger of falling into the river and being struck by the descending span, in case one lets his head project over the open end of the walk.

As shown on Plate I, the main sheaves at tops of towers are covered by small houses built in a somewhat decorative style, and finished with flag poles. The operating house on top of the span, shown on Plate II, is also slightly decorated. It is 10 ft. square on the inside, and is surrounded by a footwalk and a suitable hand-railing. When the span rises to its full height, this house passes through an opening in the bracing of the overhead struts that extend from tower to tower. The operating house contains only the signaling apparatus and the peeper, so affords plenty of room for the operator or watchman. It has windows all around so as to permit him to see in every direction.

The peeper referred to is an apparatus to enable the operator to determine when the span has risen sufficiently high to clear the masts of an approaching vessel. As the device is covered by a patent, the

contract for designing and building it was let for a fixed sum to the patentee, who has failed thus far to provide lenses of sufficient power, consequently his work has not been accepted, and will not be, probably, until he makes the apparatus work satisfactorily. Meanwhile the operator, as a matter of precaution, has to raise the span at every passage somewhat higher than he would raise it, were the peeper in operation. This is no hardship though, because the span is raised and lowered so quickly. The best time made thus far for raising through the entire height is 34 seconds, which gives a velocity a little in excess of 4 ft. per second, or the speed for which the buffers were designed.

The operating machinery is located in a room 37 x 53 ft., the opposite sides being parallel, but the adjacent sides being oblique to each other, the obliquity amounting to about 12 °. The placing of this machinery beneath the street was really forced upon the writer, who had originally contemplated using electrical machinery and putting it in a house in one of the towers. As the engineer for the machinery contractor insisted upon using steam machinery, the writer deemed it unsafe to place it in the tower, owing to the injurious vibrations which might be set up; hence the expensive and rather unsatisfactory construction adopted for the house, which rests upon a timber grillage supported on piles and carrying 4 ft. of concrete as a floor. As the level of this floor is about midway between high and low water, the reason for using so much concrete becomes apparent when one considers the buoyant effort which the water is capable of exerting. Although the writer insisted that the side walls of the room should be caulked and made water-tight, this has not yet been done, so if in the future the machinery house be flooded, the writer must not be blamed. The timber grillage is drift-bolted to the piles by bolts, which were put down through gas pipes driven into the top timbers to serve as small coffer-dams, and thus prevent the water from rising into the concrete. These pipes do not extend up to the surface of the floor, so when the latter was finished off, they were filled with grouting.

The retaining walls are built of monolithic concrete, resting on a timber grillage supported on piles, as in the case of the machinery house. These walls are tied back by heavy adjustable wrought-iron rods passing through dead-men placed some 40 ft. in the rear of the face of the wall. This construction was rendered necessary by the

tendency of all retaining walls along the Chicago River to pitch forward and crack. There is a clear space of 1 ft. between the rear outer face of the machinery house and the front face of the retaining wall, so that in case of the wall slipping forward a trifle in spite of all precautions, the machinery house will not be disturbed.

At the north end of the bridge the rear columns of the towers rest on the floor of the machinery house, but at the south end they rest on solitary masonry piers, 8 ft. square under coping, and battered on all four faces. The masonry of each of these piers rests upon a timber grillage, supported by 16 piles driven to bedrock.

As for the main piers, as originally designed, there were to be two of them of masonry, resting on timber grillages supported on piles driven to the bedrock, which was supposed to be 38 ft. below the city datum, and to be overlaid with a stiff clay, capable of holding the piles in position. Although the writer asked on several occasions that borings be made to determine the exact depth of bedrock and the character of the overlying material, his request was refused. Afterwards, under a new administration, when borings were made, they showed the rock to be some 9 or 10 ft. nearer the surface, and that the overlying material consists principally of a semi-liquid clay incapable of retaining piles in place laterally. It is undoubtedly this condition of affairs which causes many of the river retaining walls to pitch forward and crack.

After considerable discussion, the writer gained his point and changed the style of the main piers fundamentally by substituting for each of them two solitary masonry piers, 12½ x 13 ft., under coping with battered sides, resting on a timber and concrete caisson sunk by the pneumatic process to bedrock. Naturally, these pneumatic piers were somewhat more expensive than they would have been had they been let with the rest of the work in competition. However, when everything is duly considered, the contractor was not greatly overpaid for this portion of the work.

The stone used for the piers is Cleveland sandstone, which, although not quite as good as the Kettle River sandstone called for in the specifications, is a very satisfactory material, as has been proven by its actual use in Chicago during many years.

The arrangement of the operating machinery is shown on Plate III and Fig. 4.

Two 70 H. P. steam engines communicate power to an 8-in. horizontal shaft, carrying two 6-ft. spiral-grooved cast-iron drums, around which the $\frac{3}{8}$-in. steel wire operating cables pass. As one of the lifting ropes passes off the drum, the corresponding lowering rope takes its place, and *vice versa*, the extreme horizontal travel being a little less than 12 ins. Thus by turning the drums in one direction the span is raised, and by turning them in the other direction the counterweights are raised, and the span consequently is lowered. When the span is at its lowest position, the full power of one engine can be turned on to

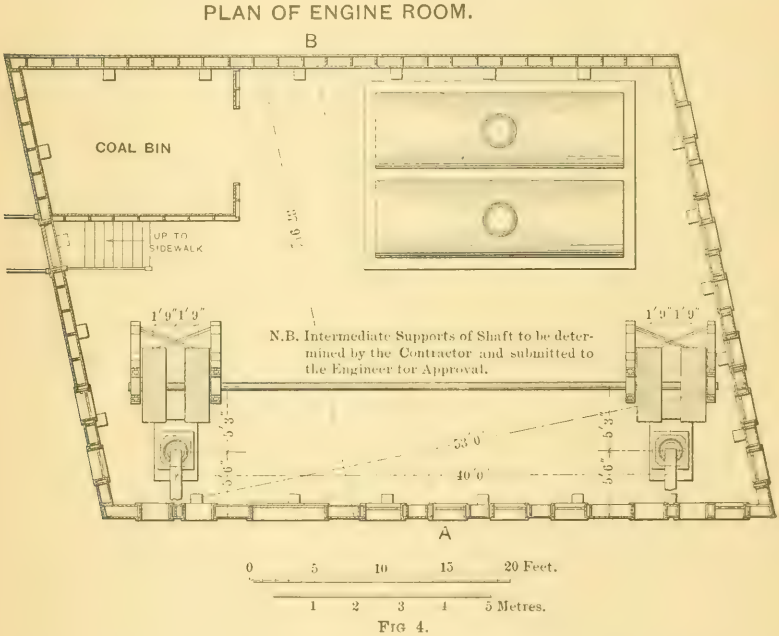


FIG 4.

pull up on the counterweights, thus throwing some dead load on the pedestals of the span, after which the drums can be locked. Before the bridge was completed, the writer considered that this would be necessary, in order to check vibration from rapidly passing vehicles; but such has not proved to be the case, for the span is very rigid, and the amount of the vibration is not worth mentioning. It is possible, though, that in some other lift-bridges, where the ratio of live load to dead load is greater, this feature of operation cannot be ignored.

The engines are provided with friction brakes that are always in

action, except when the throttle is opened to move the span; consequently no unexpected movement of the span is possible.

The stretch of the operating cables is taken up, as shown in Fig. 1, by turn-buckles near the points of attachment of rope to span and counterweights; and when the adjustment is exhausted, the rope can be shortened by loosening the turn-buckle to its greatest limit and either cutting off the outer end of the rope and making a new splice, or by overhauling it on the drum and pulling the end through a hole in the periphery, placed there to afford a fastening for said end. Each of the operating ropes stretched about 2 ft. soon after the bridge was first operated, but since then the further stretch has been very slight.

As shown on Plate III, the raising ropes, after leaving the drums, pass out of the machinery house to and beneath some 5-ft. idlers under the towers, thence up to the top of the north tower, where they pass over some 4-ft. idlers and the main 12-ft. sheaves. Four of them here pass down to the north end of the span and the other four run across to the other tower over more idlers, then down to the south end of the span.

The lowering ropes, after leaving the drums in the machinery room, pass under some idlers below the north tower, and thence up to more idlers at the top of the tower. Four of them here pass down to the counterweights in the north tower, and the other four run across, over intermediate idlers in the overhead bracing, to the main 12-ft. sheaves of the south tower, then downward to the counterweights.

In addition to the previously mentioned method of moving the span by the water ballast, there is a man-power operating apparatus of simple design in the machinery house which when used alone can raise and lower the span slowly in case the steam-power gives out, or more rapidly when combined with the water-ballast method.

The original design contemplated operating the engines directly from the operating house on the span by ropes and pulleys, as in the case of ordinary elevators; but, at a conference with the engineers for the contractors, the writer and the city's Inspector of Machinery, Mr. F. Sargent, upon their advice, decided to operate them by signals given in the operating house, transmitted to the machinery room, and, as a matter of precaution, repeated to the operating house. The writer has thus far seen no reason to regret the decision in respect to this change of design.

As the span nears its highest and lowest positions, an automatic cut-off apparatus in the machinery room shuts off the steam from the cylinders and thus prevents the hydraulic buffers from being overtaxed.

The writer expects that Mr. T. W. Heermans will discuss this paper and will give a full description of the steam machinery and signal apparatus, and will present to the Society some indicator diagrams from which can be computed the actual power required to raise and lower the span under various conditions.

Specifications that Governed the Designing.

The following is a concise statement of the leading features of the specifications, which the writer adopted when making the design.

Live load for stringers, 11 tons on a single roller 6 ft. wide.

Live load for remainder of floor system, 100 lbs. per square foot.

Live load for trusses, 4 500 lbs. per lineal foot.

Dead load for trusses, 4 100 lbs. per lineal foot.

Wind pressure for span and towers, 30 lbs. per square foot of exposed surface, including both sides of the bridge.

Intensities of working tensile stresses.

Chord bars, 15 000 lbs.

Main diagonals, from 12 500 to 15 000 lbs.

Counters (adjustable, iron), 10 000 lbs.

Lateral rods (adjustable, iron), 15 000 lbs.

Sway bracing (steel sections), 15 000 lbs.

Flanges of rolled beams (extreme fiber), 12 500 lbs.

Flanges of built beams (web resistance ignored) 15 000 lbs.

Intensities for compression members by the following formulas :

For Truss Members.

Flat ends ..... $p = 15\,000 - 56\,\frac{l}{r}$

One flat and one pin end ..... $p = 15\,000 - 66\,\frac{l}{r}$

Pin ends ..... $p = 15\,000 - 75\,\frac{l}{r}$

For Sway Bracing.

Flat ends ..... $p = 17\,000 - 65\,\frac{l}{r}$

For Pins and Rivets:

Shearing ..... 10 000 lbs. per square inch.
Bearing ..... 16 000 " " "
Bending ..... 20 000 " " "

Bearing on Masonry:

Sandstone (extra strong quality), 300 lbs. per square inch.
Concrete (Portland cement).... 150 " " "

N. B.—These intensities are for a combination of all loads, including wind pressure.

Pressure on Journals:

Upon projection of semi-intrados, 609 lbs. per square inch.

Pressure in Buffers:

Approximately ..... 200 lbs. per square inch.

Tension on Wire Ropes:

Total load for $1\frac{1}{2}$-in. cable..... 18 750 lbs.

N. B.—This corresponds (by experiment) to an initial factor of safety of about nine and one-third.

Pressure for Screw Threads of Rear Column Pedestals:

Approximately ..... 600 lbs. per square inch.

Shafting:

Intensity on extreme fiber for combined twisting and bending ..... 10 000 lbs. per square inch.

Minimum Thickness of Metal:

Below roadway ..... $\frac{3}{8}$ in.
Above roadway..... $\frac{5}{16}$ "

Velocity:

Greatest velocity of span..... 4 ft. per second.

It will be noticed that the assumed dead load makes the span weigh only 533 000 lbs., while the actual weight is about 580 000 lbs. Of the latter amount, however, some 50 000 lbs. are concentrated either at or very near the ends of span (for instance, the weight of the hydraulic

buffers, water tanks and their ballast, end floor beams, portal girders, rollers, etc.), and do not affect materially the stresses in the trusses; consequently the assumed dead load is about right.

Extracts from the General Specifications.

The following extracts from the general specifications, upon which the contract for building was let, will give a correct impression as to the quality of the materials in the structure, and the manner in which it was built. The extracts will be taken in the regular order in which the various items mentioned appear in the original specifications, and will be condensed to the greatest extent that is compatible with a clear understanding thereof. In fact, in some places, instead of making extracts, the writer will simply describe tersely certain portions of the specifications, especially those which are standard.

Piles.—Straight, live, white oak timber, free from cracks, shakes, rotten knots and all defects; not less than 10 ins. in diameter at tip, nor less than 16 ins. at butt.

Timber in Foundations.—Yellow pine, 12 x 12 ins., drift-bolted by $\frac{7}{8}$-in. round bolts 22 ins. long, spaced not to exceed 3 ft., and driven into $\frac{3}{4}$-in. holes.

Masonry.—Regular coursed ashlar of the best description. Stone to be of the best quality of Kettle River sandstone, quarried near Sandstone, Pine County, Minn., or other stone equally good.

Backing.—Backing of piers to be of Portland cement concrete. Mortar for same to be mixed in the proportion by volume of 1 part cement to $2\frac{1}{2}$ parts sand. To this is to be added as much broken stone as the mortar will thoroughly cover without leaving any voids in the mass.

Cement.—Best quality of English or German Portland, 90% fine, with 2 500-mesh sieve. Tensile strength of neat cement 100 to 140 lbs. at one day, and 250 to 500 lbs. at seven days.

Metal Work.—All metal in span and towers to be medium steel, excepting adjustable members, which are to be of wrought iron; rivets, which are to be of soft steel, and portions of the moving parts, which are to be of cast iron. All wrought iron to comply with the Manufacturers' Standard Specifications. Cast iron to be of tough, gray iron, free from injurious cold shuts, or blow holes, true to pattern and of a workmanlike finish. Sample pieces, 1 in. square and 4 ft. 6 ins. long

between bearings to carry a central load of 500 lbs. All steel to be manufactured by the open hearth or Bessemer process. Ultimate strength of medium steel from 60 000 to 68 000 lbs. per square inch. That of rivet steel from 53 000 to 61 000 lbs.

Tests to be made according to the usual practice.

Workmanship first class in every particular.

One coat of lead paint in shop, and two coats in the field.

Workmanship on the large wheels, their axles and bearings, to be of the very best that is given in machine shops to that class of work.

Timber in superstructure to be of the best quality of white or yellow pine. Floor planks to be sized to a uniform thickness. Pavement to be cedar block and built in strict accordance with the standard specifications of the city of Chicago.

Machinery.—The entire machinery is to be bid upon in a lump sum, and is to include the following:

1. All of the machinery (of whatever kind that may be adopted) located in the machinery house beneath the street.

2. Apparatus for operating bridge by man-power, in case of break-down of machinery.

3. All operating ropes from machinery to bridge, with their adjusting details.

4. All apparatus in operating house and that leading from same to machinery in machinery house.

6. Ropes sustaining span, together with all details attached thereto and pertaining to same.

7. Rockers between ropes and counterweights.

8. Counterweights.

9. Counterweight rods with their details.

10. Straps for keeping the component parts of the counterweights in position and letting the adjacent tiers of castings slide by each other.

11. Cast-iron weights to either rest on ends of span or be attached to counterweights, so as to adjust the balancing of weight of bridge.

12. Counterbalancing chains, with their attachments to bridge and to counterweights.

13. All guide wheels on span, together with their bearings and the details by which they attach to the chords.

14. Four hydraulic buffers at top of tower and four at bottom of span.

15. Glycerine tanks and their connections to the hydraulic buffers.

16. Glycerine for filling buffers.

17. The peeper, complete, with all its attachments to structure.

18. All signals and electric alarm bells.

19. All apparatus or machinery not herein specified that may hereafter prove necessary to operate the bridge properly and satisfactorily.

Machinery in Machinery House.—Each bidder will be required to furnish with his bid an outline plan and complete typewritten description of the machinery which he proposes using. There will be no restriction as to the kind of machinery to be used, whether steam, hydraulic or electrical, but in any case it is to be first class in every particular and acceptable to the engineer. Its capacity must be such that under the most unfavorable conditions of wind pressure, unbalanced weight, etc., it will be capable of lifting the bridge to a clear height of 100 ft. above the water in 50 seconds by using one engine only, the other engine acting as a reserve in case of breakdown. The second engine must, however, be capable of being thrown into action instantly, so that the bridge can be moved rapidly out of the way in case of the too close approach of a vessel.

All parts of this machinery must have ample strength, so as to avoid all possibility of a breakdown, more especially in those parts which are not duplicated, such as winding drums, with their shafts and gearing.

Man-Power Hoisting Apparatus.—Each bidder will be required to furnish an outline plan and complete typewritten description of this apparatus. It must be so designed as to be capable of hoisting the bridge slowly out of the way of vessels in case of any serious breakdown in the machinery, and must have sufficient strength and be of simple and easy application.

Operating Ropes.—There are to be eight of these for raising, and eight for lowering, the bridge. They are to be of $\frac{7}{8}$-in. "Hercules" rope as manufactured by the A. Leschen & Sons Rope Company, of St. Louis, Mo., or other rope of the same diameter, and equal strength, quality and pliability.

The adjustments of these ropes are to be made by means of long-threaded rods of sufficient strength, and the connecting details are to be of the most approved design.

Sheaves or Idlers.—These are to be about 5 ft. in diameter, of cast iron, each cast in one piece. The workmanship thereon is to be first class.

Operating Apparatus.—Each bidder will be required to furnish with his bid an outline plan and complete typewritten description of this apparatus, which must be made perfectly effective in every particular, amply strong, quick in action, and to the approval of the engineer.

Sustaining Ropes.—These are to be 1½ ins. in diameter, and of the same kind and quality as specified for the operating ropes. There are to be 32 of these ropes, eight at each corner of the bridge. All connecting details for these ropes are to be of the best standards in use.

Rockers.—Rockers between ropes and counterweights are to be built of steel in strict accordance with the requirements of the specifications for metal work.

Counterweights.—These are to be cast as smooth and true as practicable for ordinary castings, so that they will work smoothly up and down in the guides, and so that the adjacent tiers of castings can pass each other vertically without undue friction.

Counterweight Rods.—These are to be of wrought iron, of the quality specified for the metal work, upset, and furnished with nuts and washers of standard type.

Sliding Straps.—These straps, which serve to keep the counterweights in position, are to be of wrought iron, and are to be made as shown on the drawings.

Counter-Balancing Chains.—These are to be of wrought iron, the weight per vertical foot of all chains being just equal to the weight per foot of the 32 supporting ropes. They are to be attached to the counterweights so as to distribute their weight equally over the supporting ropes.

Guide Wheels.—All guide wheels between span and tower are to be made of the pattern shown. They are to be of the best workmanship, so as to reduce the rolling friction to a minimum. The springs employed are to be manufactured according to the directions of the engineer.

Hydraulic Buffers.—These shall have sufficient capacity to bring the bridge to rest without shock from a velocity of 4 ft. per second, which is to be the greatest velocity allowed by the governors that are to be attached to the machinery in the machinery house. These buffers are to be of the most approved type, and of ample strength.

Glycerine Tanks.—These, with their connections to buffers, are to be of the best quality and ample strength.

Glycerine.—Glycerine for filling buffers is to be of the best quality used for such purpose; and as much of it shall be used as the engineer may deem necessary.

Peeper.—The peeper and all its connections shall be built to the satisfaction of the engineer; and the contractor shall pay any royalty that may be required by the holder of the patent for this apparatus.

Signals, etc.—Signals for warning passengers and for communicating with vessels, such as used on other bridges over the Chicago River, shall be furnished and put in place by the contractor, including two electric alarm bells of size and capacity to be determined by the engineer.

The span shall be erected on pontoons and shall be floated into position, but not until the machinery is all ready to connect to the bridge; and the obstruction to navigation, caused by putting the span into position, shall be reduced to a minimum.

Description of Details.

Span Details.—As can be seen on Plate II the style of span does not differ essentially from the ordinary, although it has several rather uncommon features, such, for instance, as the slight inclination to the vertical of the end post, as previously mentioned, the carrying of the posts below the bottom chord pins so as to have the floor beams below the chords, and the division of the upper lateral system by a continuous longitudinal strut lying in the central plane of structure. This last detail was rendered necessary by the great distance between central planes of trusses. The dropping of the floor below the bottom chords is required by the condition of making the distance from its surface to lowest part of span a minimum. An inspection of Fig. 2 shows that the floor beams are altogether too shallow for economy of metal therein. The same plate shows that the paved roadway is pitched from the middle to the sides so as to draw off water rapidly.

The heavy portal girders are required for two reasons; first, rigidity; and second, to take up the shock of the blow given to them by the buffers at the tops of the towers.

The pedestals hang from the feet of the end posts, and are pin-con-

nected. There is a strut passing from each of the feet to the first panel point from the end. One case in which this strut would prove useful, is, if in winter, when there is no navigation, the suspending cables were removed in order to repair them, and the span thus made to act like any ordinary span, changes of temperature would cause a bending on the extended portions of the end posts. The struts referred to prevent this, and would in such a case cause the span to slide sufficiently to accommodate the expansion and contraction. The end posts are figured to carry both the entire dead and live loads, although, under ordinary conditions, the former never travels thereby, but is taken up by the suspending cables.

The top and bottom chords (the latter being stiff in the end panels) project beyond the end panel points so as to afford connection for the rollers. Behind each longitudinal roller is a spring which keeps the roller pressed at all times against the column. Should the span tend to lurch forward, there is a stopper in each spring, which prevents such lurching from exceeding a certain limit. The connections of all rollers to the span are strong enough to withstand the wind pressure and any blow from the masts or rigging of a vessel; but should the hull of the latter strike the span, these connections would fail and allow it to swing sideways, which it would do until the vessel would be brought to rest.

The connections of cantilever brackets to floor beams around the posts, as shown in Fig. 2, have been objected to as being too elaborate for the size of the cantilevers; but the writer holds that such a detail is necessary in any case, in order to avoid direct tension on rivets. The tightly fitting straining angles at the post feet are also just as necessary as the upper connection, unless some equally efficient detail, such as an underneath plate extending from cantilever to beam, be adopted.

The detail for attaching the span to the cables is shown on Plate II and Fig. 1. Some difficulty was found in designing a satisfactory and efficient connection for the ends of the sustaining ropes. The Crane Elevator Company objected to the detail first proposed by the writer on account of expense, so at his request they submitted a design of their own. Upon examining it, the writer pronounced it inefficient, and proceeded to submit it to test, with the result that his judgment was verified. The company then submitted another similar,

but improved, design, shown in Fig. 1, which the writer judged would be strong enough to develop the full strength of the rope. Some tests to destruction proved the correctness of this surmise; and it is the writer's opinion that this design for the clips is the best and most efficient that can be made, although it must be confessed that its appearance is somewhat clumsy. Hitherto no one appears to have used clips that would even begin to develop the full strength of

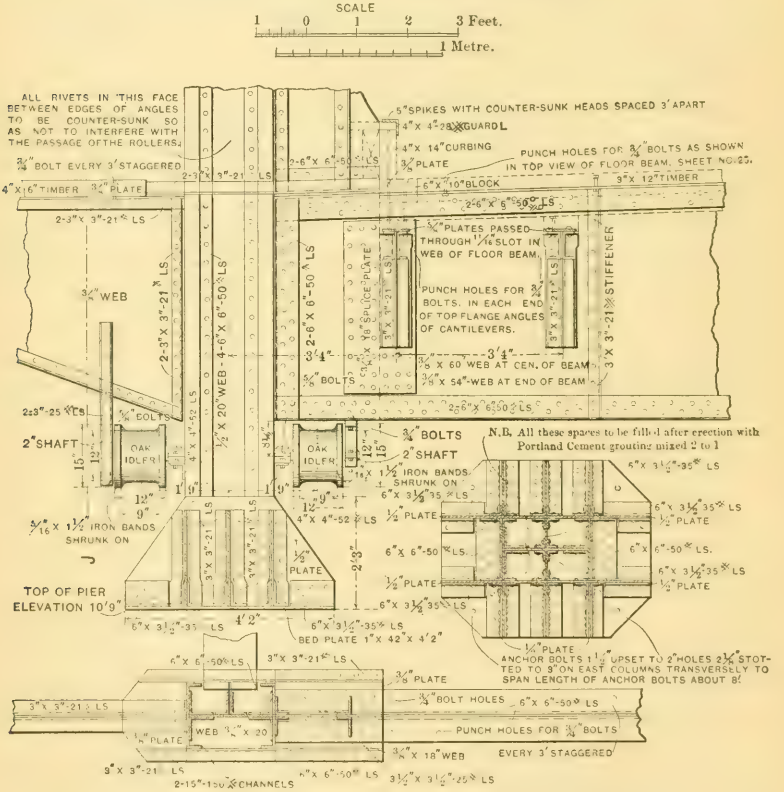

DETAILS OF FOOT OF MAIN COLUMN.
SCALE
1 0 1 2 3 Feet.
1 Metre.
ALL RIVETS IN THIS FACE BETWEEN EDGES OF ANGLES TO BE COUNTER-SUNK SO AS NOT TO INTERFERE WITH THE PASSAGE OF THE ROLLERS.
5" SPIKES WITH COUNTER-SUNK HEADS SPACED 3' APART
4" X 4" GUARD
4" X 14" CURBING
PUNCH HOLES FOR ¾" BOLTS AS SHOWN IN TOP VIEW OF FLOOR BEAM, SHEET NO. 25.
¾" BOLT EVERY 3' STAGGERED
4" X 16" TIMBER
¾" PLATE
6" X 10" BLOCK
3" X 12" TIMBER
¾" PLATES PASSED THROUGH 1⅛" SLOT IN WEB OF FLOOR BEAM.
PUNCH HOLES FOR ¾" BOLTS, IN EACH END OF TOP FLANGE ANGLES OF CANTILEVERS.
¾" WEB
¾" BOLTS
2" SHAFT
OAK IDLER
¾" BOLTS
N.B. All these spaces to be filled after erection with Portland Cement grouting mixed 2 to 1
2" SHAFT
OAK IDLER
⅝" X 1½" IRON BANDS SHRUNK ON
1½" IRON BANDS SHRUNK ON
½" PLATE
½" PLATE
½" PLATE
½" PLATE
TOP OF PIER ELEVATION 10'9"
BED PLATE 1" X 42" X 4'2"
¾" PLATE
ANCHOR BOLTS 1½" UPSET TO 2" HOLES 2½" STOTTED TO 9" ON EAST COLUMNS TRANSVERSELY TO SPAN LENGTH OF ANCHOR BOLTS ABOUT 8'
⅜" PLATE
¾" BOLT HOLES
PUNCH HOLES FOR ¾" BOLTS EVERY 3' STAGGERED
¾" X 18" WEB
WEB ¾" X 20"
¼" PLATE
2-15"-150 ℔ CHANNELS

FIG. 5.

wire rope; but in this case it is essential, notwithstanding the fact that it is contemplated to use these cables until they have lost as much as 40% of their strength.

Tower Details.—Each of the main columns of the towers is built of a single ½ x 20-in. plate and four 6 x 6-in. 50-lb. angles, forming a built I beam, which is riveted between two 15-in. 150-lb. channels

turned face to face, the web of the built I beam lying in a plane transverse to the length of span. The front face of this column is left open so as to permit of the travel of the vertical roller, but the back face is stay-plated occasionally. Wherever the rollers touch the column, the rivet heads are countersunk so as to be perfectly flush with the web. The column is expanded at the foot, as shown in

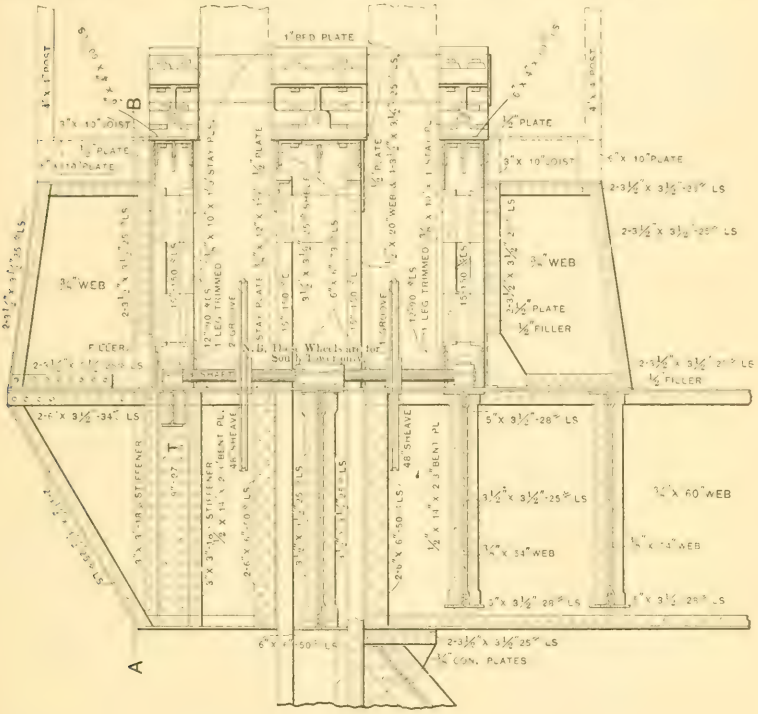


FIG. 6.

Fig. 5, so as to give a sufficiently low bearing pressure on the masonry, and so as to distribute it uniformly without overstraining any of the metal. The boxed spaces in the foot are filled with bituminous concrete.

At the top of the tower each column is expanded, as shown in Fig. 6, so as to afford proper support for the journal boxes of the

main sheaves. These boxes are lined with bronze, which is grooved spirally so as to carry the lubricant to the bottom of the bearing and distribute it uniformly.

Attention is called to the rigid character of the sway bracing in numerous planes in the vicinity of the main sheaves. No metal was spared in the endeavor to obtain the greatest practicable rigidity.

The bracing in the plane of the main columns consists of a heavy plate-girder portal near the bottom carried down the sides of the columns to the large floor beam and connected therewith, and a similar, but lighter, plate girder at the top to aid in carrying the main sheaves, and to take up the uplift from the buffers, with sway bracing of a double system of cancellation between, each diagonal and transverse member of which consists of four angles in the form of an I beam with a laced web. This system of sway bracing has a much greater strength than the computed wind stresses call for. It was put in thus for the sake of rigidity.

The sway bracing between main and rear columns consists of a single system of cancellation, all the members of same being struts, each built of two angles in the form of a star, and stayed to each other by short pieces of angle iron, spaced about 3 ft. centers, excepting two members, one of which is in the first tier below the main sheaves, and is a built I beam, designed to carry the counterweights before the span is attached to them by the sustaining cables. The other is the diagonal in the bottom panel, which is composed of four angles in the form of a star. Although these star struts make a good and rigid bracing, nevertheless, in a new design the writer would use more metal and adopt four Z bars.

The sway bracing between the rear columns is put in for rigidity only, because the figured stresses therein are insignificant. The main sheaves are built up of steel plates and angles with a cast-iron periphery grooved to fit the wire ropes. This design is a modification of one made especially for the writer over two years ago by Thomas E. Brown, Jr., M. Am. Soc. C. E., who had been called in consultation when the plans for the proposed lift-bridge at Duluth were being prepared.

Overhead Bracing Details.

As shown on Plate I, the overhead bracing between towers consists of two lattice girders built of angles and having a double system of

cancellation for the web, which changes, however, at the ends into plates. Between these girders is a system of sway bracing similar to that between the top chords of the span, and containing the same peculiar feature of an intermediate longitudinal strut. In this case, though, this strut, instead of being continuous from end to end, is made in two parts, and does not extend across the middle bay, which is left unbraced so as to permit the operating house to pass through. The detail for connecting this system to the towers is very simple and effective. It was suggested by Mr. Curtis and accepted with a slight modification by the writer. Its essential feature consists in cutting the girders (as originally designed) through the plate-girder portions near the ends by planes inclined to the vertical, so as to make the length of the top chord of the intermediate portion shorter than that of the bottom chord, facing all the cut ends with stiffening angles, riveting the short pieces on to the towers, and hoisting at one operation the two intermediate pieces with all their sway-bracing, which had previously been assembled and riveted together on the false work, so that the oblique ends met, after which these ends were riveted together, and the flanges of the girder were spliced above and below by cover plates.

Machinery Details.—As shown in Fig. 3, each hydraulic buffer consists of a cast-iron cylinder 12 ins. internal diameter and 4 ft. stroke, with a tightly fitting piston, that has through it four symmetrically disposed holes. Through each of these holes passes a tapered rod. When not in use, the head, owing to the weight of the piston, lies at the bottom of the cylinder, but, when struck, rises and forces the fluid (a light petroleum product) through the four annular spaces around the rods. As will be shown later on, the taper of the rods is so figured that the total pressure on the piston remains constant at all positions of the piston-head for any one stroke. Should the calculations have been slightly at fault, the resistance of the buffer can be increased or decreased by lowering or raising slightly the rods by means of the screw adjustment provided in the design; and should this be insufficient, it would be a simple matter to take out the rods and put in new ones with a different taper. Fortunately, though, the buffers, as nearly as can be determined by a casual examination, appear to work exactly as they were designed to do. The writer had some doubt about the ability of the piston to descend of its own weight unless it were made to fit so loosely

in the cylinder as to permit of the passage of some of the fluid around the periphery during the stroke, but his fears were groundless, for only one of the eight pistons showed any tendency to stick, and that one got to working all right in a day or two. The idea of running rods through the piston came from Edward Flad, M. Am. Soc. C. E., who very kindly placed his invention at the disposal of the writer, who personally made the original design, computations and drawings for the buffers of this bridge. This design was not varied from essentially in making the working drawings.

As the piston ascends, the total amount of metal within the cylinder is constantly increased, consequently the amount of fluid therein is correspondingly diminished, the excess passing out of a pipe at the bottom and into a small reservoir situated only a few feet above. As the pressure of the escaping fluid is quite small, the reservoir is left open to the air, and there is no loss of fluid caused thereby.

The attachment of the balancing chains to the counterweights provides for an equal distribution of the weight of the chains over all the sustaining cables, even should the latter stretch unequally.

The design for the drum, shown on Fig. 4 is very simple, and requires no further explanation.

The driving wheels for the drum shaft are placed symmetrically near the middle of the length of the latter. They are cast-iron spur wheels, 10 ft. in diameter. These and all the rest of the machinery from them towards the engines were designed by the Crane Elevator Company under the inspection of and to the approval of Mr. F. Sargent.

The attachment of the operating ropes to the span and counterweights, as shown in Fig. 1, is by means of ordinary clips, such as are used in elevators. The detail for lining up and clamping the suspending ropes was manufactured and delivered on the ground, but the bridge was found to work so nicely without it that it was decided not to put it in.

Testing.—All testing was done by Messrs. G. W. G. Ferris & Co., of Pittsburgh, who are the regularly employed inspectors of bridge materials for the city of Chicago. The usual tests of the steel were made, and the results were fairly good, considering that the use of Bessemer steel was permitted. Some very interesting tests of wire rope were made by these gentlemen under the direction of the writer,

who hopes that some of the engineers of the firm will see fit to contribute to the discussion of this paper by giving a full description of these tests, and the conclusions to be drawn therefrom in respect to the ultimate strength and other properties of steel wire ropes.

Calculations.

Buffers:

Moving weight..... ..... = 1 200 000 lbs.
Moving mass..... = 1 200 000 ÷ 32.2 = 37 267.
Maximum velocity..... = 4 ft. per second.
Energy due to same..... = 37 267 x $(4)^2$ ÷ 2 = 298 136.
say—300 000 ft.-lbs.
Number of buffers..... = 4.
Energy per buffer due to moving mass..... = 300 000 ÷ 4 = 75 000 ft.-lbs.
Stroke of buffer..... = 4 ft.
Constant pressure on piston.... = 75 000 ÷ 4 = 18 750 lbs.
Diameter of cylinder..... = 12 ins.
Area of cylinder..... = 113 sq. ins.
Area of four holes..... = 4 sq. ins. (approximately).
Net area of piston..... = 113 — 4 = 109 sq. ins. = A.
Intensity of pressure on piston. = 18 750 ÷ 109 = 172 lbs.
Hydraulic head due to 172 lbs. pressure..... = 396 ft., say, 400 ft.
Formula for velocity through holes..... $v' = 0.7\sqrt{2\,gh.}$
$= 0.7 \times 8\sqrt{400} = 112$ ft. per second (nearly).

Let v = velocity of piston at any part of the stroke. Its value will diminish uniformly from 4 ft. per second to zero.

Let A' = net area of the four orifices for the position of piston corresponding to the varying velocity v.

Then by the law of continuity—

$$A\,v = A'\,v', \text{ and } A' = \frac{Av}{v'} = \frac{109}{112}\,v = 0.973\,v.$$

For $v = 4$, $A' = 3.892$ sq. ins., and $\frac{A'}{4} = 0.973$ sq. in.

For $v = 3$, $A' = 2.919$ sq. ins., and $\frac{A'}{4} = 0.730$ sq. in.

For $v = 2$, $A' = 1.946$ sq. ins., and $\frac{A'}{4} = 0.486$ sq. in.

For $v = 1$, $A' = 0.973$ sq. in., and $\frac{A'}{4} = 0.243$ sq. in.

For $v = 0$, $A' = 0.000$ sq. in., and $\frac{A'}{4} = 0.000$ sq. in.

Let us assume diameter of plug at bottom $= \frac{1}{2}$ in.

Then area of plug at bottom $= 0.196$ sq. in.

Therefore area of hole in piston $= 0.973 + 0.196 = 1.169$ sq. ins.

Diameter corresponding to 1.169 sq. ins. $= 1\frac{7}{32}$ ins. (nearly),

Diameter of plug at top must be almost exactly $1\frac{7}{32}$ ins., so as to fit the hole tightly, but without binding.

For $v = 3$, area of plug $= 1.169 - 0.730 = 0.439$ sq. in., corresponding to a diameter of 0.748 in.

For $v = 2$, area of plug $= 1.169 - 0.486 = 0.683$ sq. in., corresponding to a diameter of 0.936 in.

For $v = 1$, area of plug $= 1.169 - 0.243 = 0.926$ sq. in., corresponding to a diameter of 1.086 ins.

If the plug were conical, the diameters at the several quarter points would be respectively 0.68 in., 0.86 in., and 1.04 ins.; consequently it will have to be swelled a little beyond the conical surface in order to make the total pressure on the piston constant at all parts of the stroke.

These calculations were furnished by the writer to the subcontractors for the machinery. How closely they adhered to them in manufacturing the buffers he cannot say; but, at any rate, the latter work satisfactorily, which is all that is really necessary. It is seldom that the span will strike the buffers with a velocity of 4 ft. per second, for two reasons, viz., first, it is not necessary to operate the bridge at such a velocity; and, second, the automatic cut-offs in the engine-room reduce the speed near the ends of the travel. On the other hand, though, if the span be out of balance, the buffers will have to overcome an extra amount of energy equal to the unbalanced load multiplied by the buffer stroke.

If the unbalanced load for an extreme case be assumed equal to 5 000 lbs., the total extra energy to be overcome will be 20 000 ft.-lbs.,

or 5 000 ft.-lbs. per buffer. This is, however, less than 7% of the capacity of the buffer.

Power.—The amount of power required is dependent mainly upon the coefficient of friction in the journals of the main sheaves. Unfortunately, but little is known concerning its probable value for such a case as this. A study of the various authorities shows a very wide range of opinion. It is well, perhaps, to assume with Morin that its value is 0.05 for ordinary working pressures and ordinary conditions.

Let us investigate three cases, viz.:

1st. No wind acting, balanced loads, and a maximum velocity of 3 ft. per second.

2d. No wind acting, balanced loads, and a maximum velocity of 4 ft. per second.

3d. Greatest assumed wind pressure acting, an unbalanced load of 2 000 lbs., and a maximum velocity of 2 ft. per second, which velocity will probably just suffice to raise the span, according to contract, 85 ft. in 50 seconds.

CASE NO. 1.

Load on journals..... = 1 320 000 lbs.

Frictional resistance of journals. = 1 320 000 x 0.05 = 66 000 lbs.

Velocity of axle in journal..... = 0.25 ft. per second.

Work of friction..... = 66 000 x 0.25 = 16 500 ft.-lbs.

Corresponding horse-power.... $= \frac{16\,500}{550} = 30.$

Inertia.—Let us assume that in 15 ft. the full velocity of 3 ft. per second will be developed.

Mass.... $= \frac{1\,200\,000}{32.2} = 37\,267.$

Kinetic energy..... $= \frac{37\,267}{2} \times (3)^2 = 167\,700$ ft.-lbs.

The average velocity during development = 1.5 ft. per second.

Time required for development = 10 seconds.

Energy expended per second $= \frac{167\,700}{10} = 16\,770.$

Corresponding horse-power $= \frac{16\,770}{550} = 30.5.$

Bending Cables.—For a velocity of 3 ft. per second, it will take approximately 6 H. P.

Summation.—The sum of these three values is equal to 66½ H. P., nearly. This seems high, and it is more than likely that the experiments about to be made will show, first, that the coefficient of friction is less than 0.05; and, second, that it takes ordinarily a greater travel than 15 ft. to develop a velocity of 3 ft. per second.

Case No. 2.

Friction.—The work of friction is directly proportional to the velocity, consequently in this case the horse-power will be $30.0 \times \frac{4}{3} = 40.0$.

Inertia.—Energy developed $= \frac{37\,267 \times (4)^2}{2} = 298\,136$ ft.-lbs.

The average velocity during development = 2.0 ft. per second; therefore, the time, as before, will be 10 seconds.

Energy per second..... $= \frac{298\,136}{10} = 29\,814$ ft.-lbs.

Corresponding horse-power $= \frac{29\,814}{550} = 54.3$.

Bending Cables.—For a velocity of 4 ft. per second, it will take approximately 8 H. P.

Summation.—The sum of these three values is equal to 102 H. P., nearly. With this arrangement of speed, the time required would be as follows:

To attain maximum velocity.....	10 seconds.
Duration of same = 116 ÷ 4	29 "
To overcome same in 4 ft.....	2 "
Total.....	41 "

If these figures are correct the bridge must have been considerably unbalanced when it was moved the full height in 34 seconds. That it was somewhat unbalanced was known, because the span went up more quickly than it went down, although the difference of time for raising and lowering was ordinarily not very much.

Case No. 3.

Friction.—For a velocity of 2 ft. per second, the horse-power required will (from Case No. 2) = 40.0 ÷ 2 = 20.0.

Inertia.—The energy developed will be $\frac{298\,136}{4} = 74\,534$ ft.-lbs., and the time, as before, 10 seconds; therefore, the energy per second will be $\frac{74\,534}{10} = 7\,453$ ft.-lbs., corresponding to a horse-power of $\frac{7\,453}{550} = 13.6$.

Bending Cables.—For a velocity of 2 ft. per second, it will take approximately 4 H. P.

Unbalanced Load.—

Energy $= 2\,000 \times 2 = 4\,000$ ft.-lbs., corresponding to a horse-power of 7.3.

Wind Pressure on Span:

Total wind pressure on span $= 50\,000$ lbs., nearly.

Diameter of roller $= 15$ ins.

Diameter of axle $= 5$ ins.

Velocity of axle $= \frac{5}{15} \times 2 = 0.67$ ft. per second.

Coefficient of friction $= 0.05$.

Frictional resistance $= 50\,000 \times 0.05 = 2\,500$ lbs.

Work of friction $= 2\,500 \times 0.67 = 1\,675$ ft.-lbs.

Corresponding horse-power $= \frac{1\,675}{550} = 3.0$, nearly.

To this should be added about 1 H. P. for the rolling friction, making the total horse-power for rollers $= 4.0$.

Wind Pressure on Counterweights:

Area exposed $= 4 \times 8 \times 10 = 320$ sq. ft.

Pressure on same $= 320 \times 30 = 9\,600$ lbs., say, 10 000 lbs.

Assume coefficient of friction $= 0.15$.

Frictional resistance $= 10\,000 \times 0.15 = 1\,500$ lbs.

Work of friction $= 1\,500 \times 2 = 3\,000$ ft.-lbs. per second.

Corresponding horse-power $= \frac{3\,000}{550} = 5.5$, nearly.

Summation.—The sum of all these values is 54.4 H. P. From this it is evident that, if the various assumptions are correct, one 70-H.-P. engine will easily raise the span 100 ft. clear above the water in 50 seconds, under a wind pressure of 30 lbs. per square foot, and with 1 ton of unbalanced load on the span; consequently the contractor has complied generously with the specifications.

Erection.—The treatment of this subject will be left to Mr. W. W. Curtis, the engineer who represented the contractors, and under whose personal supervision it was so ably done. There is but one adverse criticism to make thereon, viz., the great length of time it took; but for this there are many extenuating circumstances. Under like conditions many a contractor would have thrown up the contract in despair; and, in the writer's opinion, if Mr. Curtis had the work to do over again, with everything favorable, instead of unfavorable, he would finish it all in the contract time. It was contemplated, when the specifications were written, to erect the span on pontoons, float it into place, and raise it clear of everything in a single day; but the erection being delayed until after the close of navigation, the contractor was permitted to drive false-work piles all the way across the river. The passage of the latter for tugs was blocked in consequence only three or four days.

Estimates.—Owing to unavoidable changes in both substructure and superstructure, it is not practicable to check the total cost of bridge with the preliminary estimate, which was based upon the quantities given at the end of the "General Specifications." There is only one item of all these that it is convenient to check, viz., the total weight of metal, 1 250 000 lbs. To this must be added the writer's preliminary estimate of 100 000 pounds for raising the towers 15 ft., making the total estimated weight 1 350 000 lbs., which agrees within 5 000 lbs. with an estimate made in the writer's office from the complete detail drawings.

The reasons why the total cost of the bridge is higher than was anticipated are as follows:

1st. Increased cost of superstructure (nearly $5 000) because of the increased height of towers.

2d. Greater expense involved by the necessary change from pile piers to pneumatic piers.

3d. Adding to the legitimate cost of the structure that of removing the old pivot pier and doing considerable dredging for the purpose of deepening the channel.

4th. Extra expense for engineering and inspection due to the delay in completing the structure.

If the contract for building a duplicate of the Halsted Street lift-bridge were to be let to-day, at present prices, with close competition,

and if the engineer were allowed full sway in making plans and specifications for substructure, superstructure, approaches and machinery, based upon correct data, it is not too much to say that the entire cost would be reduced to, at most, $150 000, instead of $200 000, which is about what the structure itself really cost, exclusive of outside extras.

Advantages of Lift-Bridges.

The advantages of lift-bridges, in comparison with rotating draw-bridges, are as follows:

1st. A lift-bridge gives one wide channel for vessels instead of the two narrow ones afforded by a center-pivoted swing-bridge.

2d. There are no land damages in the case of a lift-bridge, as the whole structure is confined to the width of the street. These land damages in the case of some swing-bridges amount to a large percentage of the total cost of structure.

3d. Vessels can lie at the docks close to a lift-bridge, which they cannot do in the case of a swing-bridge; consequently with the former the dock front can be made available for a much greater length between streets than it can with the latter.

4th. The time of operation for a lift-bridge is about 30% less than that for a corresponding swing-bridge.

The advantages of a lift-bridge in comparison with a bascule or a jack-knife draw, both of these being supposed to be without a center pier, are as follows:

1st. The lift-bridge can be made of any desired span, while, in the case of the others, the span is necessarily quite limited in length.

2d. A lift-bridge can be paved, while the others cannot.

3d. The lift-bridge is very much more rigid than any structure composed of two or more partially or wholly independent parts, a feature characteristic of the jack-knife bridge or the bascule without a center pier.

4th. In a lift-bridge, the operating machinery is much more simple; and, in case that it should ever get out of order, the span can be raised or lowered either by unbalancing, or by simple hand mechanism, or by both combined.

Conclusion.—In concluding this paper the writer desires to give full credit to the following gentlemen:

Primarily, as before stated, to the Hon. J. Frank Aldrich is due the fact that the bridge is in existence.

To W. W. Curtis, M. Am. Soc. C. E., is due great credit, not only for the careful and conscientious manner in which all of his work was done, but also for his unfailing courage in dealing with continual occurrences of the most disheartening character.

To Mr. T. W. Heermans, engineer for the machinery contractor, is due the credit of the fact that every portion of the machinery went together as it was designed.

To S. M. Rowe, M. Am. Soc. C. E., the resident engineer, is due the credit of the correct location of all parts of substructure and superstructure.

To Mr. Ira G. Hedrick, the writer's engineer and chief draftsman, and to Mr. Rudolf Markgraf, his architect, are due the credit of preparing the complete detail drawings for the entire structure, excepting the steam machinery and signal apparatus, which were designed, as well as built, by the Crane Elevator Company.

It would be unfair to omit to mention Lee Treadwell, Assoc. M. Am. Soc. C. E., the writer's principal assistant engineer, who, although but slightly connected with the designing of the Halsted Street bridge, was, nevertheless, instrumental in evolving many of the special details employed therein, when studying with the writer on the design for the proposed lift-bridge for Duluth. Moreover, he assisted in making the drawings for the span of the Halsted Street bridge.

As before mentioned, the writer is indebted to Thomas E. Brown, Jr., M. Am. Soc. C. E., for many valuable suggestions concerning general details, and to Edward Flad, M. Am. Soc. C. E., for his kind permission to use his idea for hydraulic buffers.

The Halsted Street lift-bridge has now been in operation long enough to show that all that was claimed for it by its projectors was true, and that it works even more easily than was anticipated; and as the writer is now engaged on the preliminary designs for several similar structures, in which he is so arranging the manner of their operation as to reduce the cost of same below that for corresponding swing-bridges; and as the first cost of other lift-bridges can be made very much less than that of the pioneer structure, it is not improbable that in the next few years many structures of this type will be built over navigable waters in American cities adjacent to the sea-coast and the Great Lakes.

DISCUSSION.

Mr. Lindenthal.

Gustav Lindenthal, M. Am. Soc. C. E., remarked that while the paper was very interesting, there were some points which were omitted, for instance, the testing of the wire ropes. This question had recently come up in discussion in connection with the use of sockets for fastenings, and it was shown by tests that that method was unreliable, because it was very difficult in practice to pin every wire fast in the socket, and hence the full strength of the wire rope was never developed in testing to destruction.

The reason for the use of this type of bridge is given in full by the author, namely, that at the site of the bridge the U. S. War Department objected to the use of an ordinary draw-bridge as an obstruction to navigation, and that the type adopted was thought to be one which would meet those objections. He did not think, however, that this type of bridge would be used generally as a substitute for draw-bridges, because it was more expensive in first cost and more expensive to maintain.

Mr. Buck.

L. L. Buck, M. Am. Soc. C. E., stated that he had not been able to give the paper the attention which he would like to do before entering into a detailed discussion of it, but that he could not at the present moment see any good reason for raising the whole span to such a height as to permit the passage of masted vessels under it. His feeling was that, had the problem been presented to him, he would have exhausted all other resources before adopting the plan of the author. He had heard that objection to a draw-bridge was made by the War Department, but on the Erie Canal the State of New York also objects to draw-bridges. It occurred to him that raising the floor of the bridge alone might be a more desirable method. The supporting structure could then be placed above and made stationary and permanent. An examination of a draw-bridge across the Chicago River had satisfied him that a satisfactory solution of the problem might be worked out in this way.

Mr. Thomson.

G. H. Thomson, M. Am. Soc. C. E., called attention to the fact that on page 35 some of the advantages of lift-bridges are noted. One other advantage can be mentioned, viz., lift-bridges can be manipulated with ease while a stiff gale is blowing, and this has been tested with the type known as the end lift-bridge. The difficulty of manipulating circumrotary draws during gales has been experienced in both hand and power swing bridges of equal arms; while the bob-tail draw (unequal arms) presents much greater difficulties in the way of rotation.

Mr. Thomson. Another advantage in some types of lift-bridges is that the amount of coal required is less than the amount required for rotary draws of equal single span.

The statement that a lift-bridge of the bascule type cannot be paved (*sic*) will not find acceptance with those who think that there is no difficulty in laying wooden block pavement on bridges with inclined surface roadways.

He further remarked that the cost of this structure seems excessive; that how much of this cost is chargeable to substructure does not appear, and that it would be interesting to know the weight of the towers. The paper, with its accompanying plan, does not disclose this, and an economy analysis is not easily made off hand. The magnitude of the counter-weighting (given at 290 tons) is something more than an "end" lift-bridge requires. An "end" lift-bridge needs but one tower of about one-half the height, with presumably less material than the Halsted Street bridge towers.

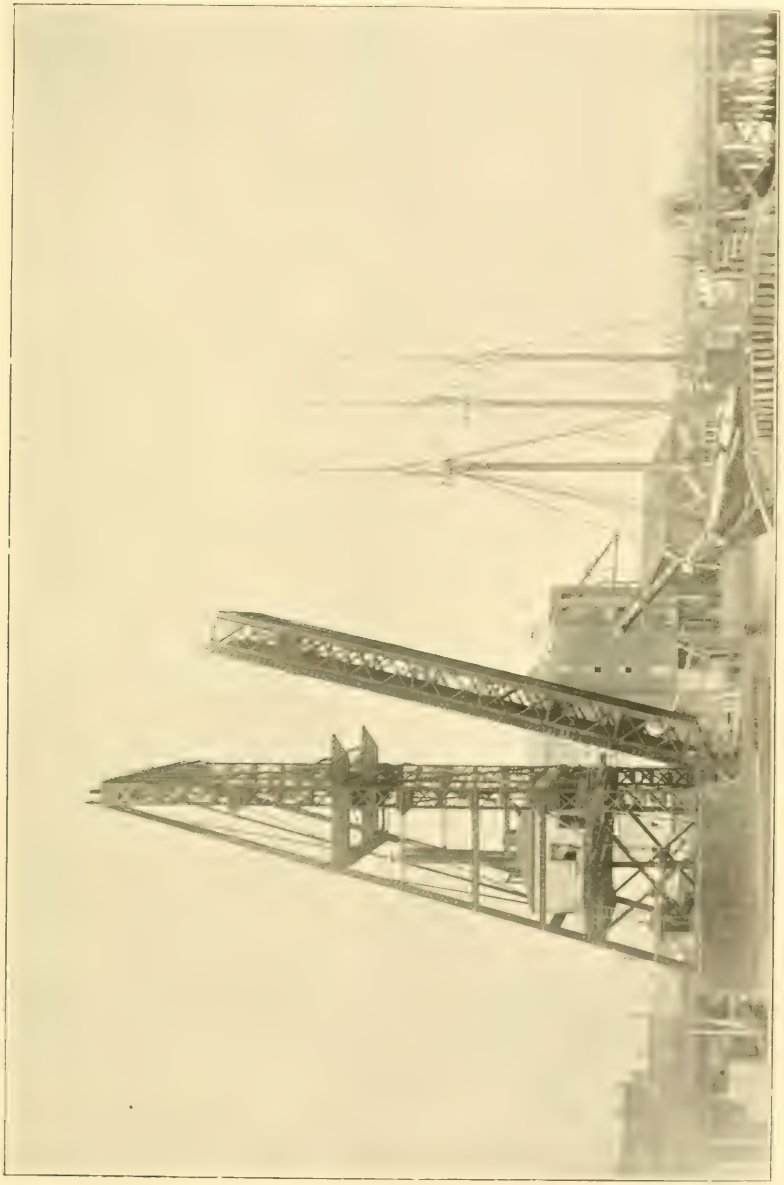
He called attention to an end lift-bridge designed for W. Katté, M. Am. Soc. C. E. (see Plate V), a view of which shows a double-track end lift-bridge on temporary line over the Harlem River, of a total length of 106 ft., center of end pin to extreme end. It has been lifted about 50 times a day for about six months, and one and one-half minutes is the usual time of a full lift, and it is responsive in action.

The Halsted Street bridge is rapid in movement. One double-track through plate (of 60-ft. span) end lift-bridge has been lifted to the full height in nine seconds.

He thought the selection of any type of lift-bridge should be the result of mature deliberation after weighing all the conditions presented in each particular case; that some situations point to the selection of a lift-bridge as justifiable, whether viewed in the light of first cost or cost of maintenance, while others admit of no other type of draw, but that the usual conditions presented by most situations permit the use of the rotary draw, and economy and other matters indicate soundness of judgment in its adoption.

Mr. Skinner. F. W. Skinner, M. Am. Soc. C. E., complimented the author on the excellent manner in which he had presented the paper, and called attention to the elaborate and unusual screw adjustment at the base of the towers, which he presumed had been very fully studied, but which at first glance seemed to be somewhat remarkable. As adjustments would require to be made very infrequently at most, it seemed to a casual observer as if it would have been better to simply arrange for differential loose packing plates and the temporary insertion of hydraulic jacks, than to use costly steel screw bearings.

He said further that the design of bridges that should cause the least interruption of traffic on the numerous highways and waterways of large cities is a subject that had lately received special



attention by a large number of the most prominent bridge-builders. Notably interesting and original designs were prepared by the late Mr. Scherzer, and the engineers associated with the elevated road in Chicago, while the author had carefully developed a fundamentally distinct line of construction. He called attention to a type of bridge differing from that described by the author, consisting essentially of a bascule bridge, the leaves of which are made to slide back, with their centers of gravity moving always in a horizontal line and revolving about them until they reached the wide open position, of which type there is a bridge in Milwaukee already completed, and another for which George H. Benzenberg, M. Am. Soc. C. E., has prepared plans of a structure without any towers. By this arrangement the distortion by necessity for absolute adjustment and danger from settlement is considerably relieved. Mr. Skinner.

Charles E. Emery, M. Am. Soc. C. E., desired to add his testimony to the very thorough way in which this subject had been presented. In regard to the type of bridge, he thought that those engaged in actual construction were best fitted to criticise, but as there seemed to be a difference of opinion among them, he might be permitted to remark that apparently something more in the way of land damages might have been allowed, and a simpler bridge placed at that site. The raising of a span of only 130 ft. to such a great height would seem to be unnecessary, for had the whole span been lifted in one direction, the tower spanning the river would not have been required and the load to be lifted have been reduced one-half. It might be, however, that the conditions were much worse than appear in the paper. Mr. Emery.

T. J. Long, M. Am. Soc. C. E., said that the only point which occurred to him was the statement of the author that one of the advantages of this type of bridge over the bascule and jack-knife lift-bridges is that it can be paved, while the latter cannot. His impression was that the Tower Bridge, of London, which is a bascule bridge, is paved, and that the two bridges of the jack-knife lift type in Chicago are also paved. Mr. Long.

J. Sterling Deans, M. Am. Soc. C. E., said that he was not prepared to discuss the details of construction, but would state that he had heard objection made to this special design of draw, by one of the assistant engineers of Chicago, on account of the great cost for operation. He had since heard, however, that a large proportion of this cost was due to some defect or inefficiency in the machinery and not due to any defect in the design of the structure proper. Mr. Deans.

Lee Treadwell, Assoc. M. Am. Soc. C. E., remarked that in regard to the question of wire rope the tests made were very interesting, and he was sorry that they were not embodied in the paper. The author expected, however, that their results would be given in the form of a discussion by G. W. G. Ferris & Co., who made the tests. When Mr. Treadwell.

Mr. Treadwell. tested the rope parted at a point between and removed from the fastenings, showing thereby that its full strength was developed, and that the efficiency of the fastenings was all that could be desired. According to his recollection the maximum strength of a 1½-in. steel cable was found to be 175 000 lbs., or about 15% less than its estimated strength. The breaking strength of wire rope, as given in manufacturers' catalogues, is generally arrived at by multiplying the strength of one wire by the number of wires in the cable.

He desired to say, that about six weeks ago he went up on the Halsted Street bridge, and that the buffers worked in a perfect manner, there being absolutely no reaction such as is felt when an ordinary passenger elevator is brought to a stop.

Answering Mr. Buck, he said, that in working up the design for a proposed lift-bridge at Duluth, which finally led to the Halsted Street bridge, a number of different designs were carefully considered by the author, one of which was with a fixed span at the top of the towers, but, that when the cost of the span, together with the cost of the suspended floor and all the necessary cables, drums, counterweights, pulleys and attachments were considered, it was believed that there would be little or no saving in cost over the movable span. He thought a more serious objection, however, to the fixed span and suspended floor was that the long chains or cables going down to support the floor could not be protected from the weather and the swaying action of the wind. Moreover, a floor 130 ft. long and suspended by cables 155 ft. in length would be seriously lacking in rigidity, especially under the passage of heavy coal wagons and similar loads. The design was therefore abandoned as being entirely inadequate to meet the requirements of the case.

The unusual conditions that affected the Halsted Street crossing he considered to be eminently favorable to the lift-bridge type of construction. A rotating draw, with its pier and protection piles occupying a space 60 ft. wide by 200 or more feet long in the middle of the river, would interfere seriously with navigation interests, for the river is both narrow and crooked at Halsted Street. A counterbalanced swing span, with one short arm and the pier on the shore, could probably have been constructed for a little less than the cost of the lift-bridge, but the damage to private property and the occupation of about 300 ft. of wharfage would have more than offset the saving. Moreover, such a span, not permitting of a complete rotation through 360 degrees, would require more time to open and close. There being continuously heavy traffic on Halsted Street, the item of time in opening and closing any bridge for the passage of boats was therefore a most important consideration. The lift-bridge was built entirely within the street limits, there being no damage to private property and no interference with boats receiving or discharging cargoes at the

adjoining wharves. He stated, also, that so far as he was able to learn when in Chicago, the lift-bridge is giving better satisfaction to both navigation interests and to the general public than is any other bridge over the Chicago River. The average time that street traffic is interrupted for the passage of a vessel at the lift-bridge is said to be less than the corresponding time at the swing bridges. Mr. Treadwell.

As to the cost of the bridge, he said that no bridge-builders in this country had previously had experience with a structure of this kind, and consequently they bid with a large margin for contingencies. In addition to this, the contractor was required to give a bond for the successful operation of the bridge, according to the requirements of the plans and specifications, namely, that it should be raised 100 ft. in 50 seconds. The approaches and machinery house were included in the cost of $200 000. He believed that the bridge could now be built for something like $50 000 less than that amount.

In regard to the operation of the bridge, he was told recently by the day signalman on the span, that, excepting with the engines, not the least difficulty had ever been experienced in operating the bridge. Some weeks ago the main driving pinions on the crank shaft of the engines were broken, through rough usage by an inexperienced engineer, and, as a consequence, the span remained at the top of the tower for a period of 36 hours, at the end of which time the repairs were completed and the bridge again put in operation. He said another reason that the engines have not given perfect satisfaction is, that they are run at a much higher rate of speed than their designers ever intended that they should run. Instead of raising or lowering the span at the rate of 2 ft. per second, as required by the specifications, it is generally moved at the rate of 3 or more feet per second: hence there is a tendency to shake the engines to pieces and to loosen the connections.

He further remarked that the force required to operate the bridge is a large item in the expense account, three engineers, two signalmen, four policemen, and one man to shovel coal, clean the machinery, oil bearings, etc., being required to make up the shifts for 24 hours. The cost of operation is said to be about $1 000 per month during the navigation season. He understood, however, that the author would in future designs use electrical power and make such other modifications as to reduce the operating expenses to about one-half of the amount given, depending on the weight of the bridge and the local requirements.

Foster Crowell, M. Am. Soc. C. E., thought that the author in speaking of the jack-knife construction refers to a structure of two parallel folding girders, and that those spoken of by Mr. Long were modifications of the bascule type. The old-fashioned jack-knife bridge evidently could not be paved unless the supports were made entirely Mr. Crowell.

Mr. Crowell. free from the floor, which is impracticable. The pavement on the Halsted Street bridge he believed was wooden blocks, which would not be a great weight on a bridge of this length. While a permanent pavement would be a desirable thing, it does not seem to be a very serious matter.

He understood there was a report that the annual expenses of maintaining the Halsted Street bridge would be about $150 000, and that when a bridge of the same type as this was recently in contemplation not far from New York City, the authorities abandoned the idea on account of this expense.

CORRESPONDENCE.

Mr. Heermans. T. W. HEERMANS, Esq., said that in describing the construction, erection and operation of the machinery designed and erected by the Crane Elevator Company for the operation of the Halsted Street lift-bridge, it would, perhaps, be well to consider the subject under the following heads :

1st. The general plan and arrangement of power-house.
2d. The determination of power required.
3d. Type of engines to be used.
4th. Methods of connecting gearing to drum shaft.
5th. Mounting of the drum shaft and gearing.
6th. Friction clutch used in connection with gearing.
7th. Method of piping and running engines.
8th. Counterweights.
9th. Method of setting counterweights.
10th. Cable fastenings.
11th. Method of connecting cables to span.
12th. Water counterbalance.
13th. Hand-power operating device.
14th. Signaling device.
15th. Peeper.
16th. Suggestion for ascertaining power required for operation.

First.—In the general plan and arrangement for the machinery in the power-house, ample space had been set aside by the engineer for the machinery, and consequently the only requirements were that the best use possible be made of this room, so that the machinery be readily accessible for maintenance or repairs. This was accomplished by placing the boilers on one side of the engine-room, with their fire doors towards each other, and sufficient space between them for fire irons or for renewing the flues in the boiler when necessary.

This arrangement of boilers allowed the engines to be placed centrally in the engine-room, with their working end readily accessible and near the firing space. It was so arranged that the man in charge of the machinery, in caring for his boilers, would also be near the engines and operating levers when any signal is given from the operating house on the span. The engines were connected with the drum shaft by spur gearing, and are clearly shown on the plans submitted with the paper, which show, also, what other arrangements have been made with respect to the machinery. Mr. Herrmann.

Second.—The determination of power required for operating the span has been very thoroughly gone into by the author in his paper. The figures made by him, or rather the results arrived at, were similar to those obtained by the writer. The proportioning of the gearing is such that the piston travel of the engine is to the motion of the bridge or span as 500 is to 158, making the pressure available on one piston equivalent to a disturbance of the balance between the bridge and the counterweights (with 100-lb. boiler pressure and the span uniformly balanced) about 20 000 lbs. This appears, from all experiments made, to be ample for overcoming the inertia and friction. No absolute data has yet been ascertained as to the amount of power required to start, accelerate and keep the bridge in motion, but this matter is now being considered by the city engineer, and experiments will doubtless soon be made that will give reliable data.

Third.—The type of engine used for operating the machinery is one built by the Crane Elevator Company, and used largely in the steel plants for operating the transferring cables, cranes, etc., and is of the steam reverse type. While this engine is not as economical in the use of steam perhaps as some link motion engines, its construction is so much more simple that, like the valve motion used with steam pumps, it has come largely into general use where such engines are employed, and receive a maximum amount of use and minimum amount of care.

Moreover, as the engines are standing for a large portion of the time, it is easy to make steam for them, as the fires under the boiler may be kept in more uniform condition.

Fourth and Fifth.—The method of connecting the gearing to the drum shaft was such as to admit of the removal of any of the gears without disturbing the machinery. In other words, should any one of the gears forming the two trains of gearing connecting the engines with the drum shaft be broken, it might be removed in a short time without disabling the operation of the span.

Sixth.—The friction clutch used in connecting or disconnecting the engines from the drum shaft was of special design, and made necessary by the position in which it was placed. These clutches are of the Weston type, and are set up by a wedge and toggles operated by a screw passing through a stationary nut.

Mr. Heermans. *Seventh.*—The plan or method of running the piping was arranged so that both engines are fed from a main header or drum supplied by independent pipes from the two boilers, thus making it possible to use either or both the boilers, as well as either or both the engines. In addition to the ordinary throttle valve, which is operated by a lever easily reached from the operator's position, a small by-pass valve was supplied, having an area of a ½-in. pipe. This valve is kept continuously open on both engines, so that the chests of these engines are kept supplied with steam at boiler pressure. The chests are also provided with steam traps for removing the water of condensation. It will be readily understood that with this connection, either engine can be placed in commission instantly by opening the throttle valve. In practical running it is customary to keep both engines in gear, allowing the one not used to be driven by the other. The small quantity of steam passing through the ½-in. by-pass valve, being of so small importance, is immaterial, and the advantage gained of being able to throw in the engine not in use instantly by opening the throttle valve is of much more importance.

Eighth.—The arrangement of counterweights was very clearly explained by the author. These counterweights, it will be remembered, are in 16 groups, each group being carried by a double cable, having its bight at the counterweight, and the two ends at the suspension pin on the span.

Ninth.—The method of setting these weights was as follows: Wrought-iron stirrups were placed over a girder built in the construction of the tower near their highest point of travel, and to these suspension bolts I beams were fastened that would bring the bottom of the counterweights to a point 1 ft. below their highest position. The weights were then raised to the platform thus constructed, and placed in their cage or guides by a small contractor's engine. The counterweights when thus set form four groups, each group containing 44 weights, and each weight weighing about 3 200 lbs., and were then ready for the suspension cable fastenings.

Tenth and Eleventh.—The cable fastenings for these suspension cables have been referred to by the author, and consist of an equalizing sheave on each of the four sections of each group, and clamps through which the suspension pin passes at the opposite or span end. These clamps were rendered necessary by the distance between the cables where they passed over the sheaves, this distance being only 2½ ins. It was necessary to get some fastening that would securely hold the ends of the cables, and not occupy more room than the 2½ ins. mentioned above. These clamps are made of cast steel, and are clamped together with reamed bolts. The cables were measured to length, and fastened in them before they were delivered at the bridge, the only work required at that point being the lifting of the cables in position and the driving

of the pin through the clamp on the span. When this was done, the span which was then in position was lowered by jack screws until the suspension cables were taut. It will be remembered that the counterweights were within 1 ft. of their highest position, consequently the span, when lowered on the cables, had yet 1 ft. to move before it reached its lowest position. This was easily accomplished, allowing the sustaining platform under the weights to be removed, and the operating cables from the power-house to be attached to both the span and the counterweights. Mr. Heermans.

Twelfth.—The water counterbalance and its connections, mentioned by the author, consist merely of balance tanks on the span and a 2 000-gall. tank in one of the towers of the bridge, with supply pipes that can be used at the lowest position of the span or at its highest position. The tank on the tower is kept supplied by the boiler pumps in the engine-room, either of which can be used. It is also arranged so that steam can be admitted for the purpose of keeping the tanks thawed out in winter.

Thirteenth.—The hand-power device is simply a series of pawls arranged in much the same manner as on a ship windlass and for the same purpose. The proportion of lever arms is such that the power of two men applied to the end of the brake handle will operate the bridge.

Fourteenth.—The signaling device is operated in much the same manner as similar devices used on shipboard, with the exception that its connection to the moving span must be in some manner that will admit of transmitting signals while the span is in motion.

Fifteenth.—The peeper, which is referred to in the paper, has been set in position on the bridge, but, owing to the use of soft coal by the tugs and steam barges, it is not entirely satisfactory, as it is difficult to keep the lenses clean, and without being clean they are not satisfactory. It is not difficult, however, without the use of the peeper to so gauge the height of approaching vessels as to raise the bridge to the necessary height to an absolute certainty, and in actual practice the operator acquires the necessary skill without the use of the peeper.

Sixteenth.—In regard to ascertaining the power required for operating the bridge, many plans have been suggested as to the most feasible test. The writer has suggested that a hydraulic cylinder be placed in the position of the friction clutch and used as a driver in actuating the drum shaft. A pipe leading from this hydraulic cylinder to a recording gauge could be made to draw a card of the pressure delivered at that point. This card could be divided, the spaces corresponding with the seconds during which the bridge was in operation, and points made on it with every revolution of the driving shaft to which the hydraulic cylinder is attached. With this it would be extremely easy to ascertain

Mr. Heermans. exactly the amount of power required at any given second, as well as the power required in starting and accelerating the motion. Such information would be extremely interesting, and it is to be hoped that at some future time such data will be obtained.

Mr. Rowe. SAMUEL M. ROWE, M. Am. Soc. C. E., said that as his connection with the erection of the Halsted Street lift-bridge was in a certain measure vicarious in this, that he represented the designer, so far as minor matters, in connection with the work that did not especially require his personal attention, and as the author had treated the matter of mechanical construction and operation of the bridge quite exhaustively, it would seem most proper and profitable that he should confine himself in discussion to those side matters of which he had especial knowledge and which might possess some interest in practical engineering.

A cursory examination of the river-bed by means of a long iron rod showed a mean depth of water over the whole breadth of channel of about 18 ft., but below this the earth was very soft, allowing the rod to penetrate some 6 ft. further almost without pressing it.

It was first understood that rock existed here at a depth of 35 to 40 ft., and on this basis the plan contemplating pile and grillage foundation for the main pier was based; but, after pressing the matter, permission was obtained to make two borings, one at each dock, to definitely determine its level.

One hole was put down about midway between where the two main caissons were since sunk at the south tower, driving 4-in. casings to depth of about 20 ft. An earth auger was used to clean the pipe and to extend the boring below.

Progress of the boring was slow and tedious on account of the yielding nature of the clay, and it was only by repeated returns of the auger that it was penetrated, the walls closing in immediately on withdrawal of the auger. At about 26 ft. a firmer clay was found and rock was supposed to be struck, but which proved, on sinking the caissons, to be fragments of limestone embedded in the hard clay overlying the rock.

The boring at the north bank showed much the same formation, the harder stratum overlying the rock being slightly thicker. On reaching the rock with the pneumatic caissons its true elevation was found to be at about 30 ft. below Chicago datum at the south piers and about 1½ ft. deeper at the north piers.

He said that in relation to a foundation they reasoned thus. Using Chicago datum, which was here only a little below ordinary water level, and placing the elevation of the bottom of the grillage, which would be the elevation of the cut-off of the piles, at minus 15 ft. there would be a length of pile of only from 14 to 16 ft., four-fifths of which would be in a very unstable material. The remaining one-fifth, should the pile

reach the surface of the solid rock, would hardly afford that degree of Mr. Rowe.
stability that would seem to be required to insure against lateral movement of the pier.

He thought that when it is considered that the bridge is a piece of mechanism, in which any distortion from this source would be exceedingly mischievous, if not fatal, it would be seen that safety requires that the masonry should go to the rock. The fact that these piers may be subject to violent shocks from collisions from lake vessels of 4 000 tonnage, and over, either on the pier or on the span, gives force to the objections to the plans originally made.

Consequently four pedestal piers 12 ft. square were substituted for the two long ones and timber caissons were built on shore, launched into the river and floated into position. These caissons were built 18 ft. square, of hemlock timber, the walls consisting of a double wall of 12-in. square timber chamfered off at the lower 2½ ft., forming a cutting edge and roofed at about 8 ft., with three courses of 12 x 12 in. timber. The crib was built above the roof of the working chamber, a single wall of 12 x 12 in. timber with ties of the same crossing alternately in the center, to such height as was necessary to receive the base of the masonry. Of course this could only be approximated, and when the caisson reached the rock, some of the masonry courses had to be recut.

After anchoring the caisson in place, concreting was commenced and continued until the crib was filled, after which the masonry was commenced, laying courses slightly larger than the neat dimensions of the pier, to meet any tilting movement of the caisson in sinking.

When the caisson cutting edge was resting on the rock and all excavation cleaned except such fragments of rock or boulders as could be utilized in filling, all interstices under the cutting edge were chinked with concrete deposited dry and rammed into place, after which the working chamber was filled with concrete in the same manner, except that water was increased as leakage diminished. As soon as the caisson was fully sealed and such portions of the working shaft removed as was practicable by means of a wooden curb built around it, the masonry was brought in to its neat dimensions and finished.

The anchor bolts were set with a template and built into the pier.

The masonry was built of Cleveland (Berea) stone of best quality in courses from 2 ft. to 18 ins. in thickness, the stone being laid to form the face and angles, the backing consisting entirely of concrete well rammed.

The cement used was a German Portland—the Sphinx—used in the proportion of 1 part of cement to 2½ parts of good, medium sand, tempered before adding as much broken stone as it would take, the result being a very excellent quality of concrete.

The question of guarding against the movement of the abutments

Mr. Rowe. by reason of the tendency of the river banks to press toward the river channel, thus bringing into play another possible disturbing element, was early raised.

He said that most engineers are aware the Chicago River was originally a shallow slough or creek, and in making the harbor and docks as they are now found, the channel has been deepened, and large quantities of earth have been removed from the channel and deposited on the bank adjacent, and although supported by a row of piles driven close together, timbered, and in most cases anchored to piles some distance back, yet there is a tendency to slide toward the stream.

Not only does the material removed become soft and unstable, absorbing water readily, but the formation of which the river banks consist being mostly a soft, stiff, tenacious clay, shows this same tendency, only in a less degree, to move toward the unsupported side.

Many instances could be cited where the wing wall of the abutments of the Chicago bridges have been broken and the face wall tilted toward the channel, and it is presumed that the same will hold true as to any heavy building erected on the dock, only perhaps in a less degree.

To guard the bridge pier and the machinery room against displacement from this cause, he stated that a clear space had been preserved between the machinery room and the abutment, and an elaborate anchorage was planned for the abutment.

Five sets of four piles each were driven deep into the ground about 40 ft. back of the face of the abutment, and two iron rods from each set of piles connect to cast-iron washers bedded in the concrete abutment and drawn tight by nuts at the anchorage.

Notwithstanding these precautions, the wing walls have cracked through the entire depth, showing a slight tilting forward. It seems as if the anchorage should be heavier and should also be placed deeper and be reinforced by a mass of masonry concrete, to render it entirely effective.

The measurements for the location of the bridge were made with a steel tape, which was carefully compared with standard measuring rods furnished by the Pittsburg Bridge Company and found to agree exactly with 25 lbs. pull upon the tape, the tape being supported; and the rods and the tape were found to agree with a standard 200-ft. measure in the corridors of the City Hall at a temperature of 70° Fahr.

The base line for the location of the bridge was an arbitrary line parallel to the center line of the street, both north and south, but, owing to the jog in the street at the river crossing, this base line corresponded with the curb line on the west line of the street northward, and on the east curb line southward. Using a point on this base line near the middle of the river as the middle of the bridge, the center

line of the bridge was fixed by calculation at an angle of 12° 16′ to the right, and reference points on the street were set, from which all work was located. A practicable point was chosen on each dock by which two auxiliary base lines were turned from this center line of the bridge and intersecting the first base line, which enabled the engineer to fix convenient points for location of the main piers, etc. The true centers of the main posts of the two towers corresponding to the centers of the caissons were the main points located, and when erection commenced, these main posts were very carefully set. Mr. Howe.

The angles were carefully turned with the transit and calculated, and, when practicable, distances were checked with the steel tape.

From this basis every part of the foundation was laid off, even to the anchor piles back of the abutments.

The main posts over the piers were first set, the inclined posts following, and when the first section of the tower was complete, the inclined posts were adjusted by means of the large screw at the base until the main posts were plumb, after which the erection was completed, the towers reared nearly 200 ft. high, and the truss joining the towers raised as a whole and bolted into its place without the least delay, showing that the columns were accurately located, that they were truly plumb and that the shop work of the Pittsburg Bridge Company was accurate. This result was creditable to the bridge company's engineer and to Mr. Kellog, Assistant City Engineer, who did all the instrumental work on the location.

During the planning and erection of this bridge there was a feeling of doubt as to the result, a feeling of wonder at the audacity of the design, and incredulity as to its success. This was owing largely to the great mass that it was proposed to handle and the very considerable height to which it was to be raised, and, more than all other considerations, its controllability—in short, whether it could be handled promptly, moved quickly, and brought to rest safely.

W. W. Curtis, M. Am. Soc. C. E., remarked that the problem of the erection of the Halsted Street bridge, so far as the towers were concerned, was by no means an easy one. At the base about 40 ft. square, at the top 180 ft. above, the tower was less than 11 x 40 ft. in the clear. The members to be handled were in some cases over 58 ft. long, the main post sections being 48 ft. long, and weighing over 5 tons. The best method of handling this work seemed to be by means of a traveler to pass up inside the tower; and such a traveler was designed 12 ft. x 30 ft., in plan 40 ft. high to the foot of two derricks, placed on the top. The width of 12 ft. was too great to clear the top, but it was intended to erect all but the cross girders between the tops of the rear columns with it, and then handle these and the large sheaves by derricks erected on the top of the work, then up. The traveler was erected on the ground, one section of tower put up, and Mr. Curtis.

Mr. Curtis. then, by means of blocks attached to the top of the four columns in place, the traveler was hoisted bodily through two panels, and supported on beams running from front to rear face of tower. This was repeated to the top, three hoists in each tower being required. This traveler weighed 20 tons, and as the drift between blocks when raised into its new position was only about 12 ft., with the blocks attached to the bottom of the traveler, which extended above some 60 ft., and during the lower lifts with a large side pull, due to the tower being much wider than the traveler, the operation was one requiring great care. To add to the difficulties, the first lift made, after being completely successful so far as the raising was concerned, through carelessness in placing on the beams on the second level, resulted in a complete wreck of the traveler, with loss of life. Being satisfied that the plan adopted was the correct one, a new traveler was built, and an attempt made to devise some attachment which would make a repetition of the previous disaster impossible. After consideration of various schemes, automatic stops, etc., such as are in use on elevators, a system of counterweights was adopted. A snatch block was attached to the same chains to which the blocks for hoisting the traveler were fastened, and through these was passed a steel cable, one end attached to one of the corners of the bottom of the traveler, the other to several yards of stone threaded on an eye-bolt. These four counterweights weighed slightly less than the traveler, leaving a very small amount to be handled by the four lines carried to the engine. Other lines attached to the counterweights and carried to the ground and passed around snubs gave absolute control of the machine, regardless of the engine. It was soon found the time to attach the counterweights was a small item, and the added security fully compensated for the lost time.

He thought that the expense of erection of such a bridge as this is very heavy, that possibly there might be some more economic method than that described, but he was not prepared to say that he would follow it in another bridge. There are various slight changes in design, which would much simplify the erection if the same method were followed.

The main sheaves, built up of plates and angles, are worthy of illustration, as being something new, at least as far as his knowledge extends, and well adapted for special uses. Such a sheave would be desirable only where the load to be carried by it was excessive; or possibly where a high velocity was necessary. It seemed at first that a cast sheave could be made to answer the purpose, costing less, but on asking prices on such a construction, it was discovered that the steel wheel could be built cheaper than the cast one. As an illustration of a bridge shop's method of doing machine work, he offers the following description: By referring to the drawing of the

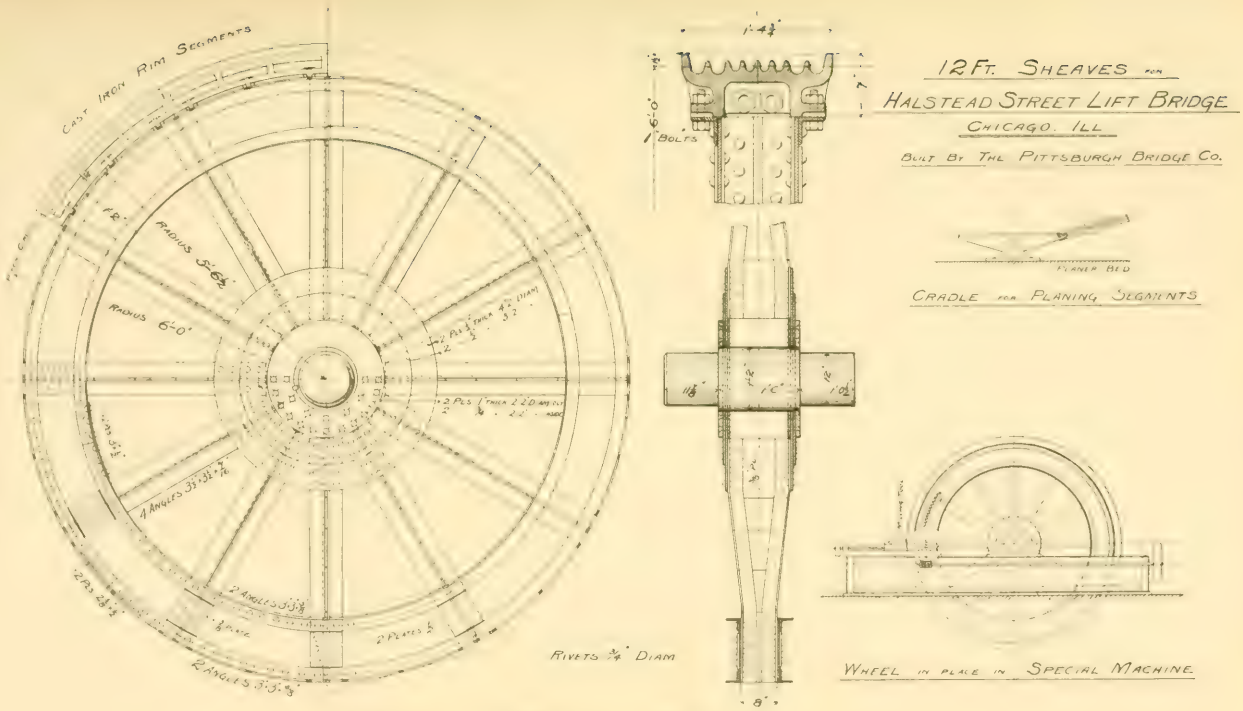

CAST IRON RIM SEGMENTS
RADIUS 5'-6½"
RADIUS 6'-0"
4 ANGLES 3½"x3½"x⅜"
2 ANGLES 3½"x3½"x⅜"
2 PLATES ½"
2 ANGLES 3½"x3½"x⅜"
2 PLATES ½"
1'-4½"
1'-7"
1'-6"
BOLTS
RIVETS ¾" DIAM
8"
12 FT. SHEAVES FOR
HALSTEAD STREET LIFT BRIDGE
CHICAGO, ILL.
BUILT BY THE PITTSBURGH BRIDGE CO.
PLANER BED
CRADLE FOR PLANING SEGMENTS
WHEEL IN PLACE IN SPECIAL MACHINE
ELEVATION AND SECTION OF WHEEL

FIG. 7

Mr. Curtis. sheave, Fig. 7, it will be seen to consist of a cast-iron rim resting on and attached to a steel rim of plates and angles. This again is supported by steel spokes of four angles running to a steel hub. The steel shaft and hub plates having been carefully finished, the sheave was built up in a special machine, as shown. The hub piece being keyed on the shaft, this was placed in the trunions of the machine, the spokes and rim added, bolted on, the wheel revolved and trued up. The hub plates were turned on both inside and outside edges, and the spokes were milled off on inner ends, and close contact with hub plates secured. After being made perfectly true, the holes were all reamed by machine, the rivets driven by hand, and the rim milled off. The interior surface of the cast rim having been previously planed by use of the cradle attachment to an ordinary bed planer, shown in Fig. 7, the sections were attached to the wheel, the holes reamed for turned bolts, and the wheel again revolved, with the milling tool replaced with one which turned out the eight grooves at one operation. When completed, the rim sections were all match marked and numbered, removed and shipped loose. The result when the sheaves were in place on the towers was very satisfactory and creditable to the carefulness of the shop superintendent, Mr. A. T. Nichols.

He remarked that one of the many points of skepticism as to this bridge on the part of the general public related to the effect of wind on it. And while to an engineer such evidence is neither necessary nor conclusive, it was worthy of notice that during the construction, the span, with the floor and all other surfaces which would be exposed to the wind when the work was complete, was hoisted to the highest position and left up at night for about a week, during which time occurred one of the most severe wind storms ever experienced in Chicago.

In such a structure the dead loads in the towers are so great and the necessary bracing to support the main section so large, that the wind does not enter into the question of design.

He called attention to the fact that the author had very clearly indicated the points of merit in lift-bridges. They are not adapted for general use, and cannot pretend to compete with a draw-bridge where this is admissible. For special locations, however, he believed their advantages are great, and for the condition of a railroad crossing, where a center pier is inadmissible, and the span over 100 ft., such a design is far superior to any other.

He further remarked that the only unfavorable criticism that has been passed on the Halsted Street bridge since its practicability and efficiency were demonstrated mechanically has reference to its first cost and operating expense; but that for both of these there is ample excuse in this particular instance, and the improvements provided for in future designs will modify greatly these objections.

E. Sherman Gould, M. Am. Soc. C. E., thought this paper and its discussion was very interesting. In commenting upon it, he wished to do so under great reserve, since the structure belongs to a class of work somewhat out of the line of his own specialties. Mr. Gould.

The oral discussion, at the time of reading the paper, turned mainly upon the design of the draw, that is, as to whether the principle of the direct, vertical lift, the tipping up on end, the horizontal swing, or the doubling up, or "jack-knife," idea, is the true one. It is evident, *a priori*, that in this, as in all other engineering problems, local circumstances enter as important factors—frequently controlling ones. He would be willing to take it for granted that an important engineering problem so carefully studied on the ground by an acknowledged expert, as this was, had received the best possible solution for that particular case.

But passing to the general thesis, it would seem that the direct lift has much to recommend it on its own merits. The author claims that the time consumed in operating such a bridge is about 30% less than for a corresponding swing-bridge. This, no doubt, applies to the particular case, but if the proposition can be generalized, and made to apply to the class, it constitutes an advantage that it would require many drawbacks to offset. A draw-bridge is at best a make-shift, and in a busy city an almost intolerable nuisance, and whatever system shortens the duration of the interruption to traffic which its operation occasions must be, on the face of it, the best. One point struck him at once: There must be many craft which only lack a few feet of going under the draw when in place. For these a very short hoist suffices; whereas, in other systems, so far as known to him, the draw must be either shut or open to its full extent. Indeed on an emergency the draw could be lifted when loaded, which would be impossible with any bascule system.

It seems clear that the strains in the lift draw must be more uniform than in any other system. There is no change in their character, whether it is open or shut. As a mechanical principle, the direct vertical lifting of an object seems the simplest and smoothest way of removing it, when it is desirable to disturb the object as little as possible.

The comparative cost cannot, he believed, be determined upon general principles; each case must be a special one. He would be inclined to think that the operation of a lift draw would be nearly always more satisfactory than that of any other system, but that its cost might frequently be the greatest.

F. W. Wilson, Jun. Am. Soc. C. E., remarked that the author states that "should the rigging of the vessel, however, strike the span, the effect will be simply to break off the masts without injury to the bridge." It appeared to him that the effect of such a collision is possibly Mr. Wilson.

Mr. Wilson. underestimated, although the author states that it has occurred once with the results mentioned. The use of wire rope in the rigging of vessels is now so common that if the masts should be well stayed by wire guys, it would seem that the effect might even be serious, particularly if the wire ropes became entangled with the truss span, and in case the headway of vessels was such as to make a sudden stop impossible.

He would like to inquire how it occurred that when the engines broke down and the span was left suspended for some hours that the many devices described in the paper for meeting such emergencies were not called into play. For example, the water ballast, the additional counterweights, and the hand-operating arrangement.

He thought that a detailed statement of the total cost would be an interesting addition to the paper, and that it would at least be more satisfactory to know how much of the $200 000 was expended for substructure.

Mr. Wagner. Samuel Tobias Wagner, M. Am. Soc. C. E., stated that in reading this valuable paper his attention had been attracted to the following general points which are of interest.

In all large cities where swing, draw, or lift bridges must be used there should be laws requiring the use of automatic gates across the open ends of both roadway and sidewalks when the bridge is open for the passage of vessels. Such places are specially dangerous to street traffic of all kinds, and some suitably designed automatic gates should be used wherever it is practicable. He thought it is rather surprising that in a city operating as many movable bridges as Chicago there are no existing laws bearing upon this subject. In a railroad grade crossing there is a chance of the trespasser not being struck by a train, but the result of stepping or driving off the open end of a movable bridge is a sure one.

The matter of the operator in the house on the bridge being sure that his signals to the engine-room have been understood is one of importance under the existing conditions, and repeating the signal is a good way of avoiding trouble. He remembered having seen on a lake steamer some years ago an automatic electrical device connecting the pilot-house with the engine-room, which enabled the pilot by means of different sounding bells by night, or by colored signals by day, to tell immediately whether the engineer had obeyed his signal. The use of this device was occasioned by a steamer running into a swing-bridge at Buffalo through a misunderstanding by the engineer of the pilot's signal. This was only another instance of the value of automatic machinery for safety appliances.

In specifying the steel to be used for a bridge of any kind, in view of the existing knowledge of the metallurgy of the metal, he would always specify: "All steel to be manufactured by the open-

hearth process, and all eye-bars to be of acid open-hearth metal," and thus exclude the use of the Bessemer process. This is on account of the uniformity and homogeneity of the open-hearth product as compared with the Bessemer. The words of Mr. H. H. Campbell, in a paper on the "Open-Hearth Process," read before the International Engineering Congress in August, 1893, and published in the *Transactions* of the American Institute of Mining Engineers of that date, express his views. Mr. Wagner.

"Uniformity and homogeneity, therefore, are two of the most important factors in the comparison of the merits of the Bessemer and open-hearth product; but unfortunately no conclusive testimony can be given to the skeptical or even the careful mind, although *ex-parte* arguments are easily constructed. No one conversant with the facts doubts that Bessemer heats can be made which are as homogeneous throughout as any open-hearth charge as was ever melted. No one doubts that in good practice the proportion of Bessemer heats which are not homogeneous is a small percentage of the whole number. But the question is not as to the homogeneity of 99 heats; it is about the quality of the hundredth. And it is not one single test of this hundredth charge that is required, but a large number of tests taken from all parts of the cast. One piece of steel differing radically from the rest wipes away all favorable arguments drawn from any number of other tests indicating homogeneity. The foregoing comparison of the open hearth and converter may not be a convincing argument against Bessemer metal. It may justify engineers in using the cheaper article in many structures, but it will also sustain the more cautious members of the profession who refuse to incur a known or a probable risk."

He added that the author does not say whether he has specified any chemical analysis for the steel in this structure, and it would be interesting to know what was done in this direction. Probably it is not fair to the manufacturer to give both physical and chemical requirements, but in view of the history of the failures in steel, it does not seem safe to omit giving a reasonably low limit for phosphorus in the specifications.

HORACE E. HORTON, M. Am. Soc. C. E., remarked that the author gives portions of the specifications for the work. In the way of discussion it occurred to him that further extracts from the specifications under which this work was built might be interesting. Mr. Horton.

"Contractor" * * * "for the machinery" * * * "shall give the city of Chicago a bond for the sum of $50 000" * * * "as a guaranty for" * * * "successful operation of the bridge, and this sum shall be collected from the bondsmen and retained by the city of Chicago in case said contractor fail to make the bridge operate successfully."

"Substructure is to be paid for upon completion and acceptance thereof by the commissioner of public works, but the remainder of the work will not be paid for until the bridge is completed and accepted."

"Hydraulic buffers are to be designed by the engineer and contractor's expert jointly." * * * "All apparatus or machinery not

Mr. Horton. herein specified which may hereafter prove necessary to operate the bridge properly and satisfactorily."

"At any time before the bridge is accepted, should the commissioner of public works decide that any apparatus not covered by this specification is necessary to the successful operation of the structure, such apparatus shall be furnished and put in place by the contractor without extra charge."

Such, he wished to state, were the conditions presented to contractors. They were asked to give bonds in the sum of $50 000 forfeiture upon failure to make the structure a success, and no prudent man will undertake work under such stipulations at ordinary profits. There were no plans of machinery. Several tenders were, however, made for the work under the harsh conditions outlined.

The only detail of the fixed structure the author describes at any length is the ball and socket screw adjustment of the rear bent of the tower, which he implies cost extra money. The sketch Fig. 8 clearly shows adjustment to be impossible, except as the pedestals are moved upon the masonry. He ventured to suggest that the author in future designs for lift-bridges will eliminate the ball and socket screw adjustment for back bent of towers, because there are many ways to accomplish the adjustment, which will "adjust" beyond any question or argument.

He believed that the ability the Halsted Street bridge to withstand the shock of collision with moving vessels can best be shown by experience.

There can be no argument, he thought, as to the necessity of something other than the pivot draw-bridge under the conditions existing in Chicago. The Chicago River, which is the harbor, approximating 200 ft. wide between dock lines, with a demand for bridges at every street of 60 ft. in width, real estate adjacent, of such value as to preclude the purchase of property to allow a pivot bridge to be swung from one side of the river. In fact, there should have been developed folding or lift-bridges 20 years ago. The public were very slow to recognize the necessity for change in design, and up to this time only four structures of the folding or lift type have been built (two completed and two approaching completion). The next few years, he thought, will see considerable evolution in design for Chicago river lift or folding bridges. The first example is the folding bridge on Canal Street, 32 ft. wide by 80-ft. span, which cost the city $18 per square foot of the area of the movable parts. The second structure, the Halsted Street lift span (subject of this discussion), is 52 ft. wide by 118 ft. opening, and cost the city $35 per square foot of opening. The third structure, Van Buren Street (not fully completed), bascule type, designed by the late William Scherzer, M. Am. Soc. C. E., 58 ft. wide by 108 ft. opening, cost $24 per square foot of opening. The fourth is the Metropolitan Ele-

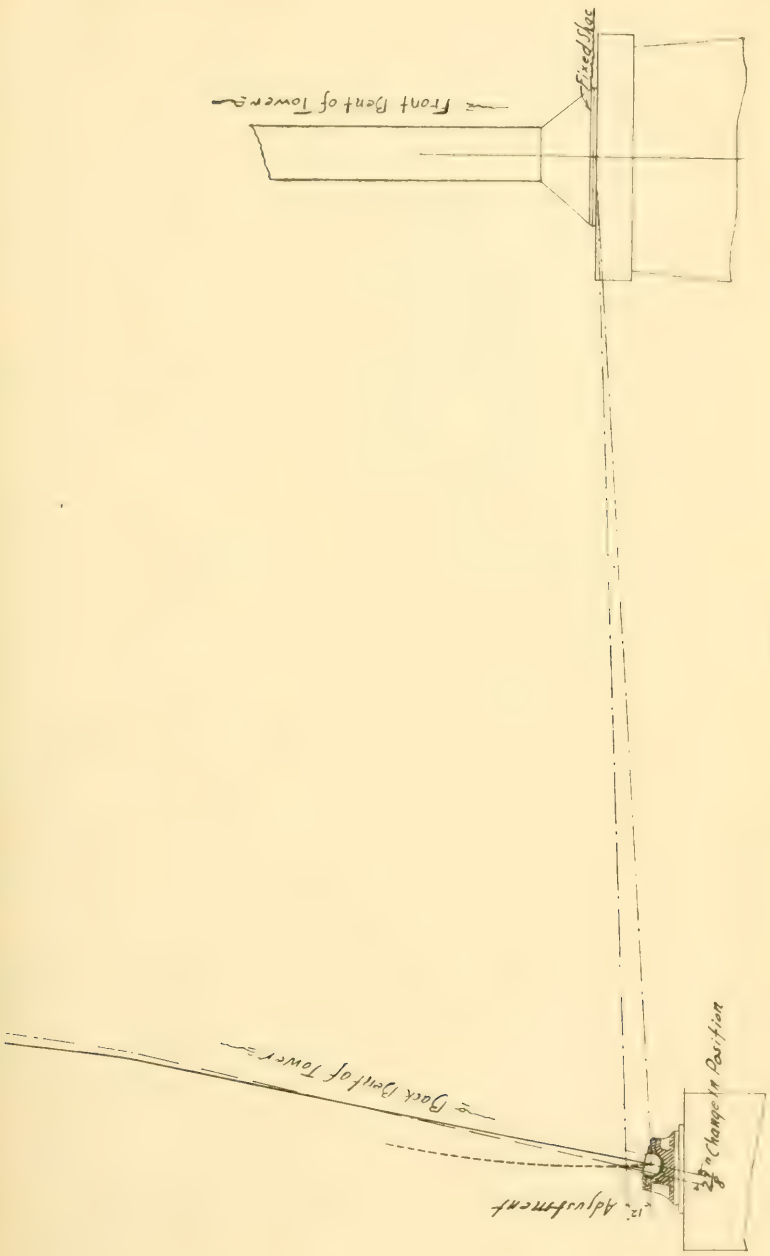

Fixed Span
Front Dent of Tower
Dock Dent of Tower
12" Adjustment
2½" Change in Position

FIG. 8.

Mr. Horton. vated Railway span, a four-track structure of the same general design as the Van Buren Street bridge.

The Halsted Street structure has been in use for some time, and has given fairly satisfactory results, leaving much to be desired, however, in the way of economy of maintenance, as well as certainty of operation.

He regretted that the author did not give particulars of the failure to operate, whereby the lift remained at its extreme elevated position somewhat over 24 hours. His understanding was that it resulted from the breakage of a pinion in the power operating gear. This calls attention to the fact that the hand moving appliance spoken of can be made of use at such times as the power operating machinery is in order, and not under other conditions.

As to maintenance, he thought the 14 000 ft. of wire rope in use on the Halsted Street bridge, of necessity to be renewed at short intervals was somewhat appalling, and that it is more than likely the apprehension of failure, and the certainty of the wearing out of wire rope necessary to manipulate bridges of this type accounted for the seeming want of confidence of both the public and engineers in such structures.

The only example that had come to his attention, of a lift-bridge other than the Halsted Street one, is the bridge on the West Shore Railway across the Erie Canal, at Syracuse, N. Y., designed by Albert Lucius, M. Am. Soc. C. E., and built by the Hilton Bridge Works, of Albany, in 1882, this structure being a double-track railroad bridge on a skew, 104-ft. span, the lift being about 8 ft., the motive power being a water motor worked by pressure of Syracuse city water. There was an interval of fully 10 years as between the building of the West Shore railroad bridge at Syracuse and the Halsted Street bridge, which is reason for the conclusion that this class of design is not a favorite.

Mr. Waddell. J. A. L. Waddell, M. Am. Soc. C. E., remarked that it was fortunate that Mr. Treadwell was present at the meeting at which the paper was read, for he was able to answer many of the questions raised in the discussion. On this account, in replying to the various discussions, he would omit all reference to those points dealt with by Mr. Treadwell.

Answering Mr. Skinner, he stated that his first design for rear column adjustment involved the use of "differential loose packing plates and hydraulic jacks"; but that he abandoned it for the reason that such an adjustment is troublesome to make, and would, in consequence, in all probability be neglected, while with the design adopted the trouble is reduced to a minimum.

Answering Mr. Long, he said that the folding bridges of Chicago are planked and not paved. It would be difficult to keep paving blocks in place when the entire floor is lifted continually from the horizontal to the vertical.

Mr. Waddell.

Answering Mr. Wilson, he understood that there had been two collisions of vessels with the Halsted Street bridge, and that the structure had not been injured to the slightest extent. A glance at the bridge is almost sufficient to assure one that no rigging, even with wire rope guys, can do it any harm.

The failure to use the hand-power apparatus when the breakdown of the engine occurred was not due to any inefficiency thereof, but because it was considered best to interrupt wagon and pedestrian traffic rather than to interfere with navigation. No one imagined at the outset that the operation of the bridge would be interfered with more than a few hours; and it was only because of a complication of peculiar circumstances (involving a strike of foundrymen) that any difficulty was experienced in getting a new gear wheel.

Answering Mr. Wagner, he stated that his original specifications stipulated the use of open-hearth steel only, but that he was forced to accept Bessemer. In the building of this bridge he was by no means a free agent, so had to make many concessions which he did not approve of, deeming himself fortunate in being allowed to build the bridge at all.

If he were to enumerate all the unnecessary difficulties encountered by both the contractors and himself from start to finish, far more space would be occupied than would be permissible. He thought it sufficient to say that until the span was hung neither they nor he could feel at all certain that they would ever be allowed to finish the bridge, such being the prejudice against it on account of a preconceived notion among engineers as well as laymen that it would be impossible to move such a great weight in any reasonable time.

Answering Mr. Horton, he acknowledged that the specifications were severe and "harsh," but would say that in preparing them he had no choice in the matter; as the city officials would not consider for a moment the building of such an innovation, unless the contractor would guarantee the successful operation of the bridge.

The papers for bidding upon were prepared under high pressure, and were made as complete as the limited time permitted; moreover, the only portions of the machinery left to the contractor to design were the steam machinery with its connections to the operating drums, and the hand-power apparatus. As the contractor was compelled to guarantee the operation of the bridge, it would have been manifestly unfair to handicap him by forcing him to use steam machinery of a design and power determined without reference to him.

As for maintenance and repairs of wire rope, he believed that, owing to the large factors of safety adopted, in all probability there will be no large expenditure necessary for many years to come.

The automatic gates suggested on page 11 have since been put in for the footwalks, but not for the main roadway. They operate very satisfactorily.

Mr. Waddell. In conclusion he desired to state that, while in making a design for another lift-bridge there are many improvements which he would introduce (principally in the line of economy of operation), he was well satisfied in every particular with all of the details of this structure; for everything worked just as it was designed to work, and there was no cutting or fitting necessary to ensure this result. Moreover, most of the important changes now contemplated would have been made in this case, had he been at liberty to design according to his own wishes. On this score, though, he desired to make no complaint, for he was well content in having had an opportunity to prove the practicability of his lift-bridge designs, even with the accompanying irksome restrictions.

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THE SANTA ANA CANAL OF THE BEAR VALLEY IRRIGATION COMPANY.*

By WILLIAM HAM. HALL, M. Am. Soc. C. E.

READ FEBRUARY 6TH, 1895.

This paper is an account of the location, design, construction and cost of the Bear Valley Irrigation Company's Santa Ana Canal in San Bernardino County, California, so far as finished for use. The writer has purposely omitted all description, even in outline, of the general system of works—canal, reservoirs, pipe lines, etc.—controlled by the company, and of which this canal forms only a part, nor is the subject of water-supply for the service at all discussed. These matters may be presented in a subsequent paper. To embody them here would make this paper too long and would detract from its usefulness in the direction sought to be given it. The relation of the new canal to the older works of the company may in a general way be understood from an inspection of the accompanying map (Plate VI).

THE PROBLEM.

The main object of the Santa Ana Canal is the delivery of water for irrigation and domestic use throughout about 45 000 acres of land of the northern portion of the San Jacinto plateau or valley. These

*The Discussion and Correspondence on this paper will be published in a subsequent number.

are now included in the new county of Riverside, but until recently were embraced by San Bernardino County. They lie between 1 350 and 2 040 ft. above sea level, sloping toward the south from the San Timoteo Hills, a range which extends south of east and north of west, and carries crest elevations of 2 500 to 3 500 ft. above the mentioned plan of reference.

Through a favorably low neck in this ridge, at elevation 2 050 ft. above base, a tunnel 2 320 ft. in length and of the capacity ultimately required, was located and constructed by the company about five years ago. This tunnel had been lined with brick and plastered with cement mortar in permanent work, before the location of the Santa Ana Canal commenced. Thus, the Moreno tunnel became the controlling point for delivery at the ridge when the location study was taken up under the writer's supervision as Consulting Engineer in 1891.

The main source of water supply for this service is the natural flow of the Santa Ana River, which is reinforced, when necessary, during irrigation months, by waters drawn from a storage reservoir within the river's water-shed in the San Bernardino Mountains, some miles above, and which are therein impounded during annual flood periods. The river debouches from its cañon course into the east end of San Bernardino Valley, at elevation 1 850 ft. above sea level, and this point of debouchment is about 10 miles in an air line (N. 19° E.) from the nearest end of the Moreno tunnel. Clearly, to deliver water by gravity flow through this tunnel, the river had to be tapped well within its cañon.

But this was not all of a controlling nature. Between the Santa Ana Cañon opening and the Moreno tunnel there lie two successive wide valleys and one long and deep cañon-like valley, with their intervening hill ranges and plateaus, and many small cañons and ridges, so that a close grade contour between these two points is probably over 35 miles, and a general contour location would probably be 30 miles in length, though the air-line distance is but 10 miles.

For the immediate purpose which was then to be subserved, the company had at the time of driving the Moreno tunnel constructed a pressure pipe line from Mill Creek to the tunnel. Mill Creek is in the first valley south of the Santa Ana Cañon opening. The pipe took supply at elevation 2 275 ft. above base, at a point 2.5 miles east of south from the Santa Ana River cañon mouth; was over 10 miles in

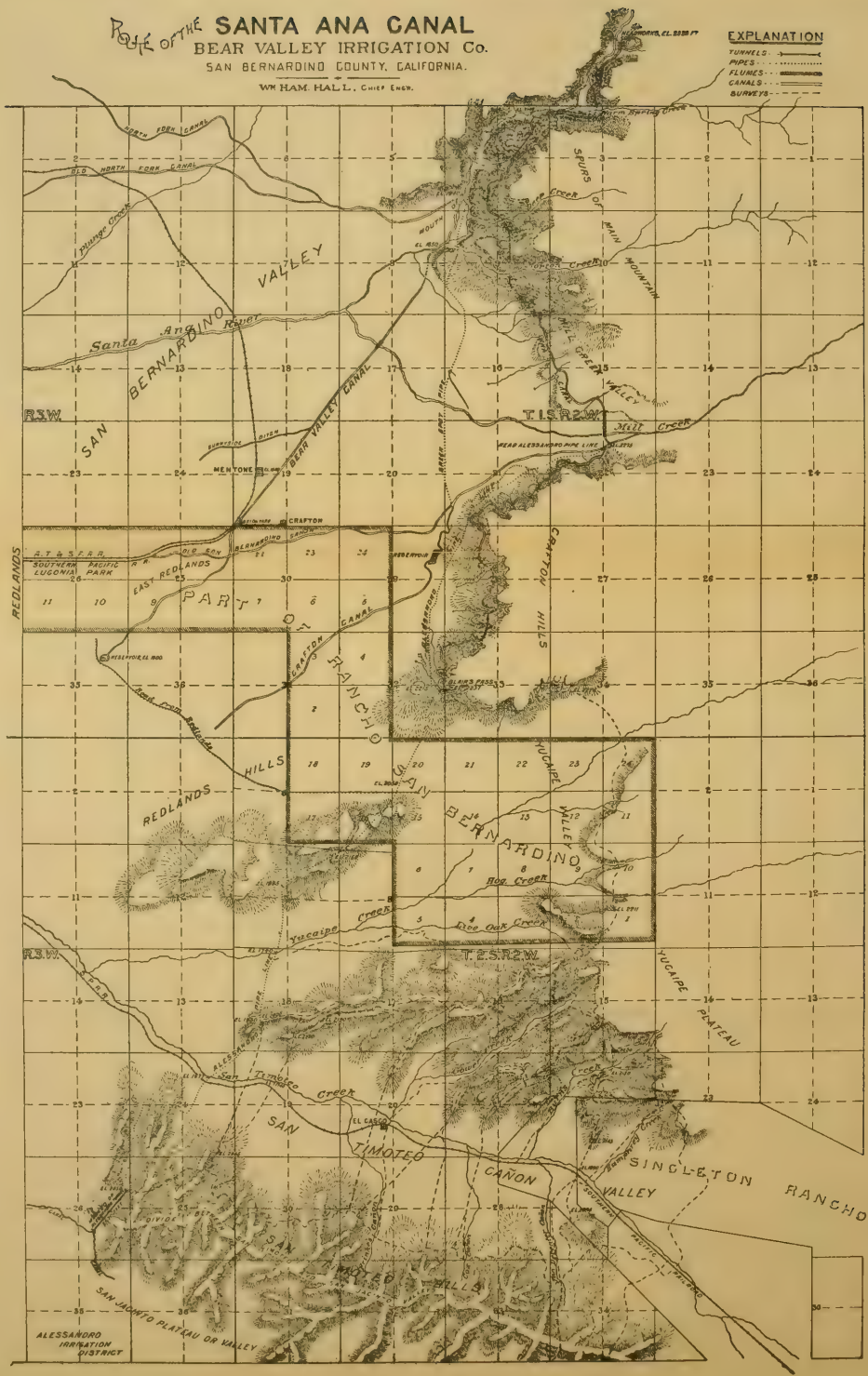

PLATE VI.
TRANS. AM. SOC. CIV. ENGRS.
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HALL ON SANTA ANA CANAL.

length to the Moreno tunnel, and was calculated for 18 cu. ft. of water per second. To realize the calculated delivery, its hydraulic gradient could not be less, and, consequently, its point of intake could not be lowered. The waters it carried were borrowed from the Mill Creek zanja, or ditch, which was not controlled by the Bear Valley Irrigation Company, in exchange for waters placed in that zanja by a work of the Bear Valley Irrigation Company from Santa Ana River, at elevation 2 100, and 1.5 miles lower down. This was a temporary arrangement entered into by the company when it had to deliver a certain amount of water through the Moreno tunnel, three years and more ago, to meet its contracts, and could not then construct the Santa Ana Canal, and had no other source at command from whence the delivery could be made. When this latter canal came to location study, in 1891, and construction, in 1892-93, the water exchange contract with the Mill Creek zanja owners was about to run out, and they refused to renew it. It was impossible, both from financial and construction reasons, to build the canal all the way to the Moreno tunnel in time, and thus it had to be located so as to deliver to the head of the Allesandro pipe line as the first controlling point.

To carry the volumes of water desired, ultimately, to be brought from Santa Ana Cañon in this aqueduct (whose annual range would be between 20 and 240 cu. ft. per second), and in the class of conduits necessary to be constructed, grades approximating 0.15 to 0.2% for flume and 0.05 to 0.1% for canal channels, were desirable, as producing about the velocities which would afford economical sections and yet could be controlled.

After certain preliminary surveys had been made, the above considerations determined about the locality where the heading would have to be, and here, accordingly, a solid rock point of mountain on the east side of the cañon was selected for the headworks, where the river-bed opposite was at elevation 2 320. This point, by the river's winding course, is about 3¼ miles from the cañon opening to the valley, heretofore referred to, and the close grade contour from it to the Moreno tunnel would be about 42 miles in length, while the air-line distance is about 12 miles (S. 23° 30′ W.).

The cañon of the Santa Ana River is walled by precipitous and rough mountains and hard rock cliffs and points, except just at the opening, where high vertical bluffs of cemented gravel and boulders

stand. Between the points of diversion and the cañon opening three large and deep side cañons come from the east into that of the main river. These are known, in the order down stream, as Warm Springs, Deep and Morton Cañons, respectively, and three other lesser but notable ones, without name, exist. Between each couple of these six cañons a high mountain point stands boldly out to the main cañon's bed. Over this portion of its course the main cañon bed, or "wash," varies between 400 and 1 200 ft. in width, and is composed of a vast mass of rounded boulders (some of immense size) and gravel, with sand in protected spots, the whole mass being at least 50 ft., and, probably, at some points, as much as 150 ft. deep. The fall of this bed averages about 140 ft. per mile from the heading to the cañon mouth, being approximately 10 to 15% more than the average at the heading, and 10% less at the lower end. On this tremendous descent the river's channel, about 80 ft. wide and 5 ft. deep, winds among the boulders. The low-water flow runs down to a very few cubic feet per second when not augmented by reservoir waters; its full-water volume ranges between 500 and 1 500; ordinary floods, 3 000 second-feet; the extreme high floods, which spread out of the ordinary channel, probably reach 20 000 second-feet in volume. The roar of waters and din of crashing rocks to be here heard at time of high flood is terrific and awe-inspiring. Such are the conditions under which a diversion dam and headworks had to be planned, and hence the selection of the place for diversion in a solid rock point, where there could be no disturbance beyond the face of the gates, no matter how terrific the flood.

The Project.

The name, Santa Ana Canal, applies from this heading to the Moreno tunnel. Beyond this tunnel the work will be divided and known as the Alessandro Canal and the Moreno Canal, besides several pipe lines, by their names. To preserve order in naming of parts and for purposes of administration during construction and in accounting for costs, the main aqueduct was set out into "divisions" and "sections," each numbered in the order of occurrence from the headworks forward; each piece or stretch of work of one character of construction and forming a measurable part of the aqueduct, together with the connecting parts and the headworks, was called a "structure," and given a number in its order. Then, each trestle

support and bridge was called a "substructure," and these in like manner had numbers assigned; and, finally, each structure and substructure of its kind was numbered. Thus divisions I and II embraced sections I to XII, structures 1 to 60, substructures 1 to 46, tunnels 1 to 9, flumes 1 to 16, pressure pipes 1 to 3, canals 1 to 10, sand-boxes 1 to 4, junction bays 1 to 7, besides other parts named in the schedule appended. The divisions were made according to ruling character of construction as dictated by topography; thus, division I covers the main cañon portion of the work, from the headworks out to the first broad valley encountered, that of Mill Creek; division II extends across that valley to the base of the Crafton Hills lying south of it; division III, around the north, west and south faces of the Crafton Hills to Yucaipe Valley lying next south; division IV, across that valley; whence division V reaches across a mesa or plateau country, and so on.

It was finally determined to plan the canal to carry 240 second-feet of water through divisions I and II, 300 ft. per second thence to a reservoir site on the line of the work, and then diminish to 200 second-feet for the remainder of the way to the Moreno tunnel. The latter figure represents the maximum volume which would ever be carried through any portion of the work beyond the cañon, for the purpose of direct irrigation. The larger volumes would represent its carriage when, in times of floods in the streams, which are of short duration, it was being used to fill the reservoirs. The larger volume beyond Mill Creek than above it includes the accession of flood waters it is intended to take from that stream when it is in flood; also for the storage purposes mentioned. The company's water contracts and engagements admitting, and its financial condition compelling, the course, it was determined to finish the aqueduct to half the ultimate capacity only, for several seasons' use, before completing any portion to full capacity. But all parts were to be planned and commenced for full size, and work was to be executed so as not only to save in immediate expenditure, but also to avoid waste and extra expense in ultimate finishing. With these controlling ideas the aqueduct has been put in condition for present use to half capacity as far as the head of the Alessandro pipe line—a length of 5.51 miles from the intake, and to within 1 000 ft. of the end of division II—thus practically covering divisions I and II. The total length thus finished is

29 095.3 ft., of which 18 175.3 constitutes division I, and 10 920 is in division II.

For the balance of the length of division II, and in subdivision A of division III—around the face of the Crafton Hills as far as Blair's Pass —the canal channel has been excavated for about 11 500 ft. in length, involving 50 425 cu. yds. of earth and rock work, at a cost of $24 204, or 48 cents per cubic yard; and 1 400 ft. of flume bench, involving 5 318 cu. yds. of material, at the same rate, cost $2 739 52. In this same division III, 1 284 ft. of excavation has been completed in three tunnels, at a total cost of $6 931 50; but these are not completed. All this work was done by contract. The topographic and preliminary location surveys have been carried to Moreno tunnel, the proposed end of the main work.

This paper deals with the parts made ready for use in divisions I and II to the head of the pipe line only. Although this covers but about one-sixth in length of the work, and, for the most part, is finished only to half capacity, the accomplished portion embraces nearly all the heaviest, and covers an unusual variety of, construction. The writer seeks herein to give prominence to those features which are thought to be novel, or which may be interesting because unfamiliar to the profession in other quarters. The balance is embodied for sake of completeness of the article and as a location and cost study.

Construction Narrative.

Construction commenced in the middle of December, 1892, but was not well under way until a month later. The heavy work was done by the middle of July, 1893. The force was thenceforward gradually reduced and the main construction was finished about the last of August, there being some odd jobs only, which occupied a very small force a while longer. Carried promptly forward, with means at command as required, the work could have been well accomplished in five months without rush or waste. Throughout, the company was in financial straits, and although provision was made for absolute necessities, and the force stuck to the work until finished as above, a demoralizing fear of failure and shutting down continuously prevailed among all classes of employees. For the four months of heaviest force account the pay days were much delayed; later, they failed to materialize at all; a panic and strike was daily feared. A spirit of

feverish unrest and uncertainty prevailed, and it is not too much to say that, from this cause, for a large part of the time, the efficiency of labor was reduced as much as 25%, and on some works as much as 40%, and its results correspondingly increased in cost. The same general cause resulted in paying higher prices than ordinary for materials of all kinds, and incidental expenses were run up in proportion.

Very much of this was unnecessary and the direct sequence of a short-sighted business management at the outset. The company started in to pay cash for everything. At first, pay-rolls had to be made out and audited so that all employees could be paid off in cash by the 3d, and then the 5th, of each month, for the month preceding; and merchant bills had to be audited for payment by the 10th. Every laborer who chose to leave work at any time during the month was permitted to draw his pay in cash, and not required to wait for a pay-day, as those who stayed on the work had to. Consequently, the employ came to be a tramp's entrance-way to paradise—a few days' work now and then enabled him to get the cash to loaf on for a week or two. The system of time checks, redeemable after 30 to 90 days, was not known. The consequence was that the company established no local credit for its small paper among merchants and others of the towns and country around. The system had not been put in use at the time when its general credit was good, and, consequently, when its greater financial troubles came, it had not the local support it should have received. Used to being paid in cash promptly within a few days after the close of each month, the employees were demoralized when a pay-day was delayed, and stampeded when time checks were issued in place of coin. When the local merchants refused to take the time checks in trade, a crisis was brought on and a general strike and suspension of work seemed imminent. Whole gangs of laborers could be seen along the line during working hours, calmly seated or leaning on their shovels discussing the situation. Teamsters, with high-paid four-horse teams, let their animals get fat on what should have been very hard and exhausting work. The general superintendent of the labor force was, by business arrangement with the former management, also the force boarding contractor and camp sutler (an arrangement, bad, from whatever point it is viewed), and the company ran largely into his debt; he became involved heavily with his supply merchants; the nervous strain demoralized and broke him down, and the watchful-

ness, vigor, activity and tact of good superintendence, of which at such a juncture the company should have had the benefit, was totally lacking. The situation was unfortunate and disheartening to a degree that was calculated to drive a responsible engineer into an asylum.

It is not for a moment thought that a wiser initial business policy with respect to these matters would have saved the company from its final disaster. The point is, that such wiser policy would have averted much trouble during the construction period, and would have kept the cost at least several thousand dollars within the estimate, instead of allowing it to run over. Nevertheless, as against a final estimate of $167 000, the work was finished at a cost of $189 600. Excess, 13.5 per cent.

And this actual result included costs not originally estimated upon at all ; as, for instance, $5 650 for roads and crossing bridges. A comparison of the total amount of corresponding items, covering the cost of the work proper, makes the excess of cost about 8.6% over the final estimate. An estimate of waste due to the unfavorable conditions commented on shows that the cost would have come about 5.4% within the preliminary estimate if the work had been carried on under normal conditions and efficient superintendence.

Owing to causes which it is out of place here to discuss, but which were in no degree whatever affected by the results of this or any of its construction expenditures, the company went into the hands of a receiver in December, 1893. It is yet thus held. There is a probability that the property will be sold to a new organization, under an arrangement thought to be such that the works will be carried to completion substantially as originally planned.

Engineering Cost Accounts.

By a system of time cards and daily force reports, to account for distribution of labor of each class on every work or structure, and on each class of construction in it, and by charging materials to structures wherein used, and keeping memoranda of use of materials within and circumstances of work on each, an attempt was made to preserve a thorough account of cost. Had the company's financial troubles not complicated and obstructed this duty, the outcome would have been gratifying, at least to the engineers engaged on the construction.

As it is, the statements of cost—though quite complete and sys-

tematically worked out from data regularly collected throughout—are to be taken with a grain of salt. The Bear Valley Irrigation Company was not in financial condition to commence a great work when it began this, and from the times of letting the first (the tunnels) contract and arranging to have a day-labor force put into the field, it was at a disadvantage to secure economical construction. Moreover, as already explained, for the last half-period of the work the force was peculiarly demoralized: everything tended to relaxation of system and care. The duty of enforcing these without overstraining was a delicate one. From personal notes by the writer and his immediate assistants, in addition to the accounts referred to, an attempt is herein made to establish a size for the grain of salt to be taken. Thus, to many concluding figures of cost given, supplementary ones are added, expressing much more nearly what, under normal conditions and good superintendence, the cost would have been.

It would be easy enough to pass these matters over and give an account of this work, implying that it cost no more than it should. As a matter of fact, considering its complexity and the novelty of many of its important parts, it did not cost more than it would had it all been carried out by contract in the ordinary way. The contractors might legitimately have made about the difference—say 20 to 25%—on the part affected. But when an engineer has labored, with a faithful force of competent assistants, to keep the cost of a notable and complicated work within a carefully prepared estimate, with a hope of making an example useful to the profession, and it unnecessarily exceeds that estimate, the writer thinks it a duty to the profession to bring out the facts. There is no reason for this in the way of personal vindication. The company officers and principal shareholders know and appreciate the cause for the excess of cost over the estimate. The engineers have not been blamed. Neither has the cost been commented upon as high, considering its class, by any one, so far as the writer knows. On the contrary, engineers of experience visiting the completed work have expressed satisfaction at its apparent reasonable cost, in view of character and locality. The reason for higher cost than was estimated, though, affords an example of a subject which, it is thought, the profession may profitably consider. As the writer has not noticed discussion of this subject before the Society, he ventures to present this example.

It may not be amiss here to say, that of all engineering service the keeping of thorough and really useful accounts of cost and performance of work the writer has found the most difficult to secure. It is not so much to be wondered at that business managers and foremen, or even superintendents, may not appreciate the utility of such data; but, to the writer, it is inexplicable that engineers who are responsible for plans and estimates, or who hope some day to be in a position to have such responsibilities, should be willing, even, to have important work go on under their direction without a record in all possible detail being made of its cost and progress.

Yet it is the exception when any such record is kept on Pacific Coast works, and many civil engineers in this region habitually demur to taking any such trouble, or they look upon an attempt at making it thorough as impractical, or declare that it simply cannot be done, or is putting on the employer a useless expense. Why should we not always know, in utmost detail, the cost of our works, as principal manufacturers and machine-shop men know to a cent what every article of their output has cost?

The Bear Valley Irrigation Company's recent work in this respect afforded an exception to usual Pacific Coast experience. The general management was in accord with the chief engineer in the desire to do good permanent work at a minimum cost to the company, and to keep an honest and thorough engineering account of it; and the engineering assistants were generally anxious to keep track of the construction details and expenditures. But the company's financial quaking not only embarrassed the manager, but kept even the engineers in a tremor. The greatest obstacle, however, was the viciously foolish arrangement, carried over from the company's former way of doing business, which fixed the superintendent of the common labor and teaming work as the boarding contractor for the day force, and so, during the financial trouble, put the work at his mercy. It is this to which attention is invited.

Observe the bad points in such an arrangement as affecting this matter of cost-account keeping.

From the very beginning the interests of the superintendent were centered in his boarding camps and not on the company's work, for had the men been paid promptly (their board accounts being regularly deducted and paid to him), he would, with his commissary store on the

works, have cleared at least $500 per month, while his salary as superintendent was only $130 per month. His interest lay in keeping men satisfied with him, whether they rendered the company good service or not. And, then, when the company ran heavily into his debt, what could be done? Had another superintendent been put in, there would have been trouble, probably a strike and failure to finish the work in time to carry water to save the company's engagement, for the men were naturally the adherents of the boarding-boss superintendent.

Another boarding contractor could not at that time have been induced to put camps into the field, and the company was not in condition itself so to do. Then followed the stage when the superintendent himself got into trouble. The company owed him $12 000 to $15 000 on board account, and the debt was increasing; he owed for supplies probably half as much, and his creditors were pressing him and threatening to foreclose on his property, for the company, his sole large debtor, was known to be in a precarious condition. The strain broke him down, nervously, and the work was virtually without vigorous handling for several months. The engineers could do nothing but hopefully cheer up the superintendent and foremen, quietly appeal to the better feelings of the men, occasionally make just a little row about the work, and generally wink at the poor service the company was getting.

And this poor service was confined not alone to the greater labor and teaming force under the labor superintendent in question, but it extended, in a somewhat less degree only, to the carpenters' force under another superintendent, although he was a most competent, faithful and energetic man throughout; for, be it understood, that the entire day labor force boarded at the one set of camps, and all became impregnated with the contagion.

The daily reports of the greater labor and teaming force were made out in the camp office of its superintendent from data which his foremen furnished on the ground, by the superintendent's timekeepers who collected the men's time for the pay-rolls. This arrangement was a mistake. The distribution of labor and consumption of material should have been daily ascertained and formulated in the engineer's office by inspectors especially instructed and competent to judge as to plans and parts of structures and classification of construction work The error was sought, after the work was well under way, to be reme-

died by appointing a special engineering accountant to supervise the making of daily reports from time to time; and, still later, by putting an engineer on duty as inspector to keep notes to check and amplify the timekeeper's daily reports; but the remedy was not all that could be desired. The mistake was made at the time when the superintendent was engaged under an arrangement which made it impossible, under the circumstances which followed, to change either him or the system after the work was well under way. Such an arrangement was an injustice to all interested elements—even to the person thus kept in so anomalous a position—as well as to the work. It was a legacy from a former management and not the fault of that which controlled during construction.

Routes.

Although for the route selected and since in part built upon, the location was controlled as already explained, and although the Moreno tunnel had been placed with the special view of its being a link in the chain of structures on this special route, when final location of the canal came to be made there was a strong element in the directorate of the company, not unsupported in its engineering department as then organized, which strenuously favored a route much higher on the general slope of the country. Moreover, the choice between these routes had for several years been a subject of debate and even dissension in the company's managerial councils, which had shaken the organization and had even caused the upsetting of a former business and engineering control.

By the upper route, diversion would have been made from the river at about elevation 3 800 ft., and after a rugged mountain course for the conduit of 7½ to 8 miles, and with several very long tunnels, the waters would have been dropped into the shed of Mill Creek; then, rediverted from that creek at about elevation 2 800 ft., they would have been carried across a plateau behind Crafton Hills, and thence, dropped to the Moreno tunnel or some other passage of the San Timoteo range.

The upper route was acknowledged to be far the most expensive for that portion between Santa Ana River and Mill Creek, but was claimed to be much the cheaper from thence to the San Timoteo Hills; it commanded additional lands and was thought by its advocates to be, all things considered, the cheapest.

A discussion of the relative merits of the two routes, with their influencing conditions and business complications, would be foreign to the purpose of this paper. The deciding argument in favor of the route selected was, that by it alone, within the time allowable, was it possible to bring water belonging to the company to the head of the Alessandro pipe line; and connected canal construction beyond that point could not be thought of until at least one, and, probably, two, seasons later.

This choice of routes and the complications produced thereby is adverted to here, and the existence of other influencing circumstances is hinted at, for the purpose of bringing to mind the difficulties and embarrassments under which the consulting engineer is often compelled to act, and for the purpose of showing the very wide range which this canal location study was forced to take.

Months and months of time and thousands and thousands of dollars had been expended by this company before the writer was called, as consulting engineer, to its councils, on surveys connected with the question of its water delivery. Yet, when the time came for the decision, the data were not available on which intelligently to arrive at one. Then, necessarily, came other months of examination and expenditure, and, finally, a decision forced on a point not involving the real merits of the case at all. Those who have our great enterprises in management, during their initial stages, have much to answer for.

It is not to be inferred that the writer thinks the wrong route has been selected for the Santa Ana Canal; there is no opinion on that point hinted at herein; but with all the advantage of time and money which was commanded and spent, here was a really great engineering and economic problem decided without going into its merits.

Engineers in the future may study this location with the advantages of perfect topographic maps covering the whole related territory. Suppose a better location, all things considered, is to be found on the upper route; in the absence of a distinct explanation of the circumstances, it probably would be incisively said, that the man who determined the route for the Santa Ana Canal did not know what he was about, or was influenced otherwise than by proper considerations, for the archives of the company would show that extensive instrumental examinations were made, and tradition would be to the effect that much time, money and talk had been expended on the problem. By such

appearances is our profession too often judged. Engineers who have its interest at heart should, as early as possible, but, at least, before closing their careers, make an available record of the true stories of such cases in their experience.

Location.

The lower route having been determined on, the location was studied upon the basis of carefully prepared topographic maps drawn to a scale of 50 ft. in the inch, and showing 5-ft. contours. These maps, for the cañon portion of the route, were platted from cross-section notes based on two connected and approximately parallel preliminary lines—the contour curves being drawn in the field, to catch intervening irregularities of the formation. The two controlling preliminary lines, carefully run in with transit and chain, and frequently connected, had a vertical interval of about 70 ft. The space between, as well as for about 30 ft. in elevation above the upper line, was closely contoured. The provisional location was projected by tangent and curve, on the maps in the office, and was laid on the ground by instruction notes made from the projection, and with the benefit of the map carried into the field for reference on a plane table.

On the basis of this provisional location, more accurate cross-sectioning was made, and from notes thus obtained a new and very close contouring of the ground was drawn in the field, upon plane table sheets, on a scale of 30 ft. in the inch. The sheets thus prepared were as accurate and full in every detail of topography of the line as they could well be made. With the first location profile also at hand for guidance, a final location project was laid down on these sheets, and carefully connected with the first location. This final location was then laid on the ground, in the manner described for the first one, and cross-sectioned for grading. And, still again, after the bulk of the rough grading was finished, the location line was again run out, offsets were taken to the grade-contour and bench's edge, and the construction line was, in places, more closely adjusted by these last data.

The object of this exceptional amount of care in location was to place a flume along the cañon's side, whose total curvature should be kept down as much as possible, whose maximum degree of curvature should not, at any point, exceed a desired limit, whose curves should be all adjusted to a few standards, and which should rest on solid and

PLATE VII.
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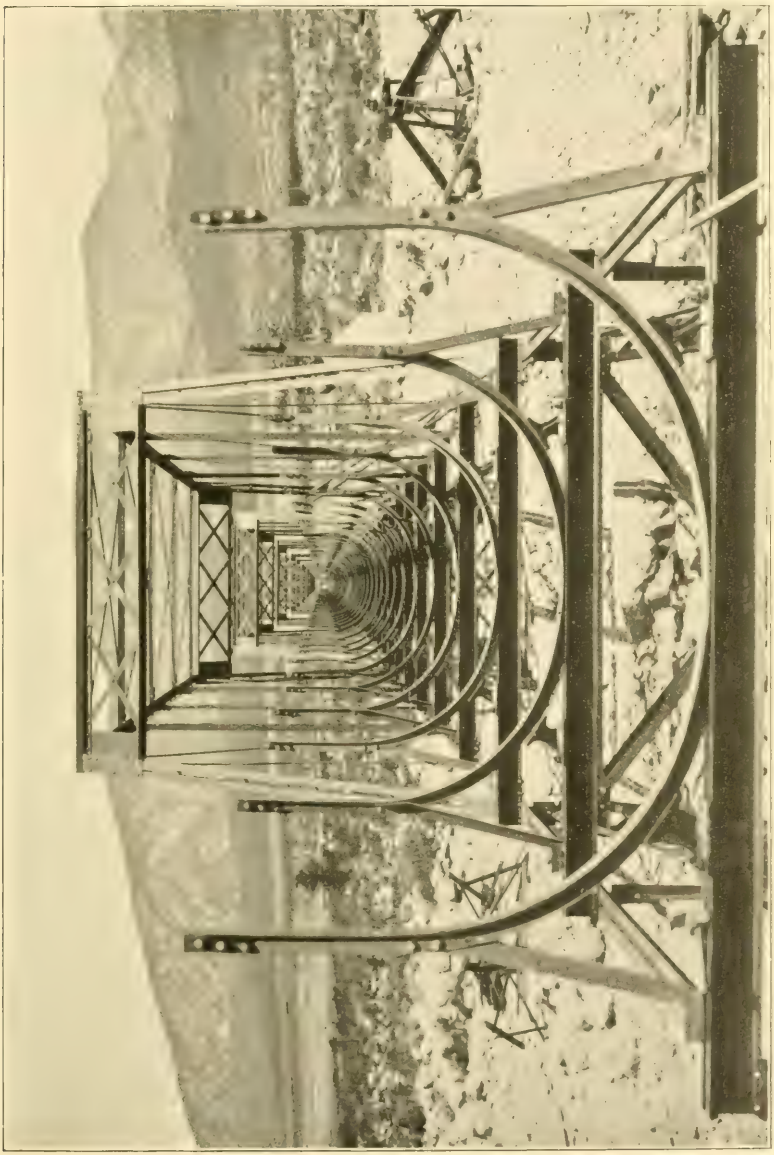
HALL ON SANTA ANA CANAL.



full-width bench as much as possible—thus limiting posting and trestle, and truss supports to a minimum—and yet avoiding unnecessary and expensive rock work. After the bench was graded, centers were instrumentally set for each bent of flume (every 8 ft.) on curve and tangent, and every footing, of which there were three to the bent, was staked by the engineers.

The instrumentation throughout turned out excellently well, reflecting credit on the assistants in charge and the instrumentmen under them. When it is known that much of this cañon side was so steep and rugged as to have been impassable before a trail was graded along it, even necessitating the use of hanging ropes to get along by, in places for several hundred feet at a stretch, and at other points, because of cliffs, not accessible at all, and that the cross-cañons were sharp and deep and the intervening points or ridges high and precipitous, it will be understood that surveys had to be repeated and checked again and often, to insure against mistake or error from accident. The tunnel alignments and grades, of which there were two about 1 500 ft. in length each, came out, on driving from opposite ends, within half an inch as a maximum error, though in neither case were the circumstances specially favorable for getting good sights away from both tunnel portals or for leveling over the mountain spurs pierced.

In division II the original topographic maps were made in the field directly on plane-table sheets, upon the basis of transit preliminaries staked in long tangents, and following the general line of grade contour, as flagged out in advance by the level. These sheets were on scale of 50 ft. in the inch, and had contours at vertical intervals of 2 to 5 ft., according to the degree of smoothness and transverse slope of the ground. Upon these sheets, as in the case of division I, a line of location was projected, and this line was run by instruction notes. On the basis of the profile of this provisional location and cross-sections therefrom, without making the larger scale topographic sheets, the final location in this division was adjusted. Though having a general appearance of smoothness as a sloping valley plain, the country transversed in this division was really rough in detail and much cut up by gulches, and the materials to be handled were, generally, heavy. The desire was to locate the canal as nearly as possible in exactly that amount of cutting which would keep its lining to the full water plane in earth, keeping down unnecessary

cutting, avoiding fills, limiting lengths of trestle and flume across gulches, and preserving directness and ease of alignment.

Construction Organization, Etc.

In division I all work, except the driving of the first eight tunnels and the construction of the three pressure pipes, was done by day labor under a company superintendent and foremen, supervised by the engineer in charge only as to technical method, adherence to plans and specifications, and acceptance of results. The handling of the force was exclusively under the superintendent. In division II the canal was excavated, but not trimmed, by contract, and all else was done by the day-labor force, as above. The company secured three acres of land for construction yards, well located where a spur from each of the two great railway systems of the country could be brought in, and here all materials were delivered f. o. b. cars. A wood-working mill, iron-working shops, and dipping vats and other conveniences were set up, and all framing and manufacturing was here executed, except making the frames and other heavy iron parts of flumes and of the steel bridge, which were delivered at the yards as manufactured material, and put up in the field and riveted, etc., by day labor. The yard was favorably located for delivery thence to the works, 3½ to 7 miles distant, and hauling therefrom was contracted at 37½ cents per ton per mile (including loading and unloading) for delivery to certain designated and numbered stations along the route, whence subdelivery was effected up the cliffs and along the work by day labor and company apparatus. The company was at the expense of all road building and maintenance, which, as will be seen, constituted no inconsiderable item of cost.

Description of the Works.

The intake, with its floor 2 323 ft. above base, is in the vertical face of a solid rock point, and a tunnel thence, 220 ft. in length through this point, brings the work out to where a side cañon enters, carrying at time of heavy rains a mass of detritus. To avoid taking this into the conduit—it being impossible to go around and over it without coming within reach of river flood waters—the location was kept into the hill, and the work so built, as a walled canal in cutting, that the side torrent might be carried over it.

Thence onward through division I the aqueduct rapidly "climbs"

the cliffs and mountain side—for the cañon-bed drops away at rates from 160 to 125 ft. per mile, while the flumes, tunnels and pipes have hydraulic gradients averaging less than 10 ft. per mile—and, by tunneling the spurs and spanning or piping the cañons, follow a contour of the mountain wall not materially longer than the general alignment of the cañon-bed itself.

Altogether, nine spurs are pierced by tunnels, whose aggregate length is 4 328.8 ft.; three cañons are crossed by pressure pipes, whose total length, as measured horizontally in the line, is 2 127.3 ft.; nine reaches of flume, having an aggregate length of 11 394.3 ft.; one piece of walled canal of 152 ft., and eight masonry walled structures in the nature of sand-boxes, junction bays and wasteways or outlets, measuring 173 ft. in line, make up the aqueduct as now finished for use in division I. In this division also there are 39 substructures, in the nature of trussed girders or combination Fink truss spans, resting upon timber piers on masonry footings, and these have an aggregate length of 1 905.5 ft.

In division II, as now finished for use, there are, inclusive of 40 ft. of junction bay, eight stretches of canal having a total length of 8 214 ft., all of which is lined with rubble in mortar except 482 ft. in fills temporarily lined with wood. Alternating with the canal reaches are seven reaches of flume, aggregating 2 706 ft. in length, crossing six sharp gulches and the wide flat torrent bed of Mill Creek. The gulch crossings are held by string girders and trussed wooden girders upon wooden piers on masonry footings, having an aggregate length of 1 440 ft.; and Mill Creek crossing is made by a riveted steel bridge 1 072 ft. long.

The following schedule names and numbers the several parts or structures of the aqueduct, and gives the length of each in the line:

STRUCTURE SCHEDULE.—DIVISION I.

Sec.	No.	Name.	No.	Feet.	Remarks.
I.....	1	Diversion dam...	..	.....	Diagonally across cañon. Not built.
".....	2	Wasteway.....	1	.....	Sluice and river by-pass. Not built.
".....	3	Headworks	..	.....	Not complete.
".....	4	Tunnel.....	1	216.0	Fully complete for 240 second-feet.
".....	5	Walled canal	..	152.0	Torrent crossing, 60 ft. Complete.
".....	6	Flume.....	1	328.0	Finished for 120 second-feet.
".....	7	Sand-box.....	1	64.0	" " " " "
".....	8	Flume	2	2 127.0	" " " " "
".....	9	Tunnel	2	208.0	Fully excavated, not lined.
".....	10	Flume	3	118.5	Finished for 120 second-feet.

STRUCTURE SCHEDULE—DIVISION I—(*Continued*).

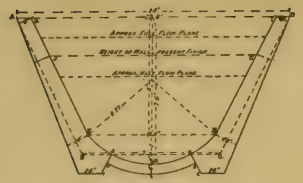
Sec.	No.	Name.	No.	Feet.	Remarks.
I.....	11	Sand-box.....	2	.....	Not built. Will replace part of flume No. 3.
".....	12	Wasteway.....	2	.....	Not complete. Will replace part of flume No. 3.
".....	13	Tunnel	3	236.0	Fully excavated. Not lined.
".....	14	Flume	4	580.8	Finished for 120 second-feet.
II.....	15	Junction bay	1	17.2	Fully complete for 240 second-feet.
".....	16	Pressure pipe....	1	540.0	Across Warm Creek. One pipe built.
".....	17	Junction bay	2	15.0	Fully complete for 240 second-feet.
III....	18	Flume	5	1 738.0	Finished for 120 second-feet.
" ...	19	Wasteway	3	.....	Incomplete. Will replace part of flume No. 5.
" ...	20	Tunnel	4	54.0	Fully excavated, but not lined.
" ...	21	Flume	6	2 418.0	Finished for 120 second-feet.
" ...	22	Wasteway.....	4	.....	Not built. Will replace part of flume No. 6.
IV....	23	Tunnel	5	1 410.0	Fully excavated. Not lined.
V.....	24	Flume	7	2 688.0	Finished for 120 second-feet.
".....	25	Wasteway.....	5	20.0	Also outlet to drop to lower canals.
".....	26	Tunnel	6	58.0	Fully excavated and lined.
".....	27	Flume	8	229.0	Finished for 120 second-feet.
".....	28	Tunnel	7	43.0	Fully excavated and lined.
".....	29	Flume	9	1 167.0	Finished for 120 second-feet.
VI....	30	Junction bay....	3	17.0	Fully complete, for 240 second-feet.
" ...	31	Pressure pipe....	2	908.2	Across Deep Cañon. One pipe built.
" ...	32	Junction bay	4	17.5	Fully complete for 240 second-feet.
VII...	33	Tunnel	8	1 594.0	Fully excavated; partly lined.
VIII..	34	Junction bay	5	16.3	Fully complete for 240 second-feet.
" ...	35	Wasteway.....	6	.....	Not built. Temporary flume built.
" ...	36	Pressure pipe....	3	679.0	Across Morton Cañon. One pipe built.
" ...	37	Junction bay	6	6.0	Penstock. Complete for 240 second-feet.
IX....	38	Tunnel	9	509.8	Complete, 240 second-feet.
				18 175.3	3.442 miles.

DIVISION II.

Sec.	No.	Name.	No.	Feet.	Remarks.
X.....	39	Junction bay	7	40.0	Incline. Lined for 140 second-feet.
".....	40	Canal	1	1 344.0	Lined for 120 second-feet.
"	41	Flume	10	141.0	Finished for 120 second-feet.
".....	42	Canal	2	244.0	Lined " " " "
".....	43	Flume	11	200.0	Finished " " " "
".....	44	Canal	3	275.0	Lined " 240 " "
".....	45	Flume.	12	328.0	Finished " 120 " "
".....	46	Canal	4	951.0	Lined " " " "
".....	47	Flume.	13	416.0	Finished " " " "
".....	48	Canal	5	527.0	Lined " " " "
".....	49	Flume	14	192.0	Finished " " " "
".....	50	Canal	6	758.0	Lined " " " "
".....	51	Flume	15	214.0	Finished " " " "
".....	52	Canal	7	3 569.0	Lined " " " "
".....	53	Wasteway.....	7	.....	Not built. Will replace part of flume No. 16.
XI....	54	Flume	16	1 215.0	Across Mill Creek. Finished for 120 second-feet.
XII...	55	Sand-box.....	3	.....	Not built. Will replace part of flume No. 16.
" ...	56	Canal	8	506.0	Finished for 120 second-feet.
" ...	57	Pipe heading.....	..	.....	Alessandro pipe line.
				10 920.0	= 2.068 miles.
		Total		29 095.3	= 5.51 miles.

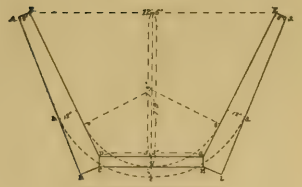
SKETCHES OF HEADWORKS AND CROSS SECTIONS OF WATER-WAY DIVISIONS I AND II.

Fig. 1



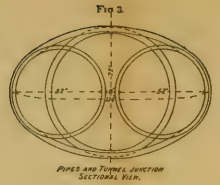
CANAL LINING - DIVISION II - CONSTRUCTION LINES ADOPTED.

Fig. 2.



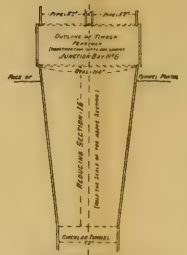
CANAL LINING - COMPARATIVE SECTIONS - CONSTRUCTION LINES NOT ADOPTED.

Fig. 3.



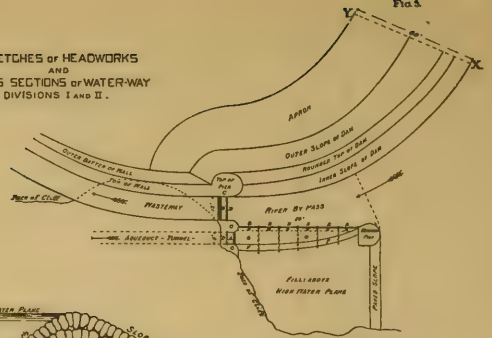
PIPES AND TUNNEL JUNCTION SECTIONAL VIEW.

Fig. 4.



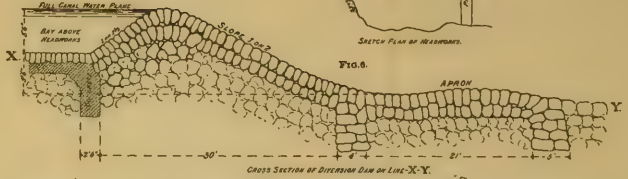
PIPES AND TUNNEL JUNCTION - BAY Nº 6. OUTLINE PLAN.

Fig. 5.



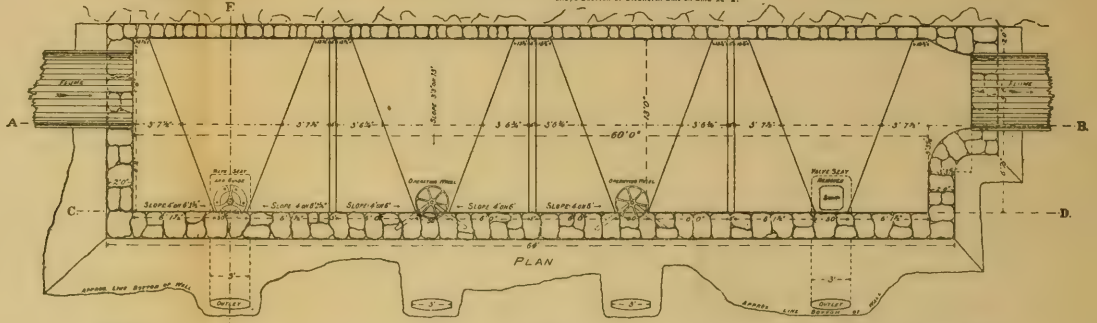
SKETCH PLAN OF HEADWORKS.

Fig. 6.

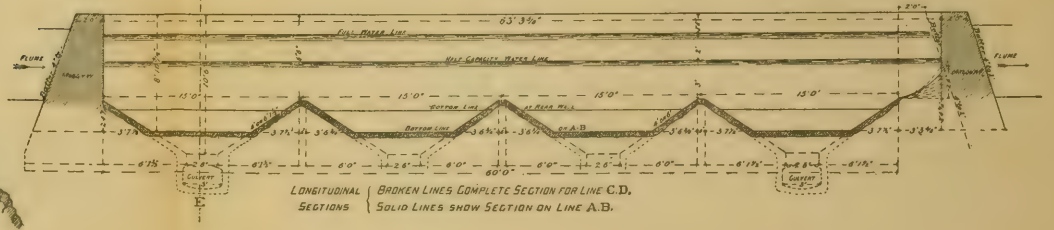


CROSS SECTION OF DIVERSION DAM ON LINE X-Y.

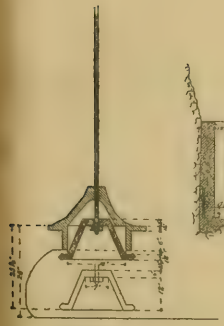
PLAN AND SECTIONS SAND-BOX Nº 1 DIVISION I



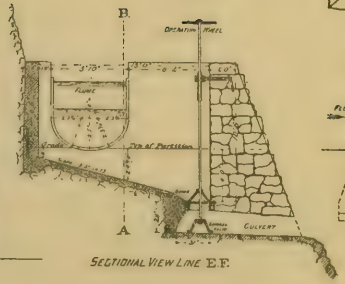
PLAN



LONGITUDINAL SECTIONS { BROKEN LINES COMPLETE SECTION FOR LINE C.D. / SOLID LINES SHOW SECTION ON LINE A.B.



SAND VALVE WITH SEAT AND GUIDE 1" × 1"



SECTIONAL VIEW LINE E.F.

Diversion Dam, Sluiceways and Headworks.

The diversion dam, sluiceways and canal headworks, when finished, will constitute one construction, but for the purpose of keeping separate the cost of each of the important parts, they enter into the engineering accounts as three structures. Only the headworks proper have to this time been worked upon, and these are not completed. There being as yet no dam, water is brought to the heading by a temporary ditch from a favorable point of intake, for the comparatively small quantity now handled, 921 ft. higher up the stream.

For the purpose of making clear this location of diversion works and the relation and expected duty of the constructed part, it will not be out of place to submit a sketch and general description of them as planned, notwithstanding so little progress has been made in their building.

The location is dictated and design controlled by the torrential nature of the stream, whose waters, even at high stages—when rolling boulders and cobbles and whisking gravel and sand of all grades along with their flood—are to be diverted into an aqueduct which must, as far as possible, be kept free from such wearing and destroying detritus. For this work is to serve not alone for delivery of water during the irrigation season, but also for transportation of flood waters to storage reservoirs along its route.

The general ideas designed to be realized at the heading are : (1) to interpose, in the form of a dam, across the river cañon as little obstruction to the free flow of its high floods as possible ; (2) to keep the ordinary flood and low-water flow of the stream permanently in a channel next to the intake ; (3) to prevent the lodgment and accumulation of detritus either at or immediately above or below the intake ; (4) to draw the clearest available waters into the canal heading ; (5) to sluice the heavier detritus and more heavily laden waters rapidly by the same.

The plan (Fig. 5, Plate VIII) shows that the heading tunnel takes water from the end of a chamber or bay 60 ft. long and 12 ft. wide ; while this chamber receives water along and for nearly the full length of its side, from the river by-pass channel which lies parallel to and is separated from it by a thin partition of movable weir shutters running in upright iron guides. Taken together, the by-pass channel and the receiving chamber form a waterway 26 ft. wide on the bottom, and with parallel sides,

in curved plan, as shown ; while, splitting and diagonally crossing this waterway, lengthwise, is the partition holding the intake weir shutters. This waterway, held between the dam on the outside and the inner wall of the chamber, leads directly to two aqueducts—one, the canal, in tunnel through the solid rock ; the other, the escapeway, on solid rock and concrete, with an outer pier and wall of masonry. The headgate, the intake weirs and the sluice gate afford the means of regulating the water's flow, as may be desired, into the one or the other aqueduct.

The floor of this double waterway, from under the foot of the dam's slope to and under the foot of the chamber's sloping wall, and from the head and sluice gates to the upper limit of the structure, is a pavement of boulders set in cement on a concrete foundation. The dam's slope is of boulders in cement, and the chamber wall is of the same slope and construction. A heavy fender pier of masonry on a deep concrete base protects the upper and exposed corner of the chamber ; and from the side of this pier a sloping wall heavily paved with boulders in cement, footing on a concrete spiling wall, extends to the cliff, to cut off possible attack by extraordinary floods, in the rear. The space between the chamber wall, this fender pier, the storm wall and the cliff, is to be graded up with material blown off the cliff above and will serve as a site for keepers' house, etc.

A rolling drop of 1 ft. at the lower end of the chamber is made to facilitate entry to the headgate, and this same object is planned for in shaping the training walls each way from the gate itself. A drop of 2 ft. immediately below the sluice gate is intended to facilitate clearance of the bay above. The sluice gate, 14 ft. wide, is made of iron, trussed behind, to move on rollers and be operated by hydraulic power. The headgate is of similar construction. Both hold within their movable frames weir shutters which can be operated independently of the framed gates as a whole. A platform overhead affords space for operation. This rests on the solid rock each side of and over the headgate which is in the masonry arched portal of tunnel No. 1, and extends thence across to the masonry pier forming the outside abutment of the sluice gate. The iron guides of the intake shutters project well above the highest possible floods, and there serve as pillars to hold floor beams extending over the chamber from its inner wall. Suitably braced, this iron framework is designed to sustain the water pressure and shock on the weirs, and also to carry an operating platform overhead. The weir

shutters or flashboards are operated by a specially designed apparatus from this platform. They are set and run so that their outer faces are flush with those of the iron standards which hold them —thus presenting an unbroken plane to the waters in the by-pass channel.

The dam is level topped from end to end, rounded transversely, and planned to be not more than 3 ft. higher than the mean height of the boulder-bed of the cañon. Its rounded top and sloping sides, extending down into the boulder mass, are intended to present the least possible obstruction to the flow of the greater floods, which are expected to go over its full length and to fill the space above it with gravel and boulders, except in the river by-pass channel, where these will be carried through by force of the concentrated current.

The features to which attention is specially invited are (1) that of taking waters into the work from the surface of the natural flow, in a thin sheet over a long weir lip, and with the least possible deflection of their line of flow; and (2) that of under-flushing the waste or escape waters down a drop past the intake. These two features, the writer thinks, embody principles on which works should, whenever possible, be planned for diversion from natural streams into irrigation canals, but which are frequently violated, even reversed in application, in many important works in our country.

The objects are, of course, to take in water and keep out its sediments, sands and gravels. An underflow gate draws from the bottom of the stream, and, because of this, is the proper design for a sluiceway—to get rid of the sands and gravels carried near or rolled along the bottom. It should not be used for an intake, for, thus used, it directly defeats one of the primary objects desired. Overflow gates, usually put in as flashboards, can be designed so as to admit of handling with perfect ease under any circumstances. They draw from the top of the stream first; and heavier detritus has to accumulate above before passing over them. They are, for this reason, detrimental in a by-pass sluiceway, but exactly applicable for intake gateways; and, where the waters are carrying sediments, the intake should be in a thin sheet over such gates, so as to draw only from the surface of the natural stream.

The arrangement of the intake openings on the side of the headworks chamber, and not in a heading transverse to the run of the stream and canal; the placing of the gates flush with the outer faces

of the piers which hold them, and the introduction of light iron piers between the gate openings, are points of design offered in this work as novel in irrigation and engineering practice and at once cheap of construction for permanent work, and purposeful to the special ends in view. These are the securing of as long an intake lip as may be desired without affording either a bay or a recess for an eddy where detritus or sediment would accumulate above the gates; and the minimizing of obstruction to, and deflection of, the current in passing from the natural stream into the canal, and in the stream itself, past the heading.

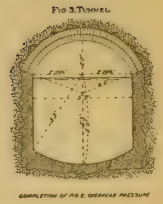
The advantage and even necessity of observing these points in design for the work under description becomes the more appreciable when we reflect that the stream in flood will come to the heading with a mean velocity of about 8 to 10 ft. per second; that this rate of movement is to be maintained in the canal; that such a current cannot be passed around large obstructions without immense disturbance; that a head-bay which would effect the lowering of velocity at time of full intake, so that corners might be turned by the waters, would be subject to silting up at a period of low flow and would necessarily be far larger and more expensive.

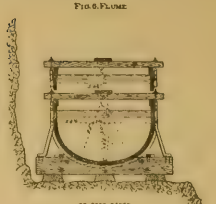
The design and location specially admit of the works being raised—carried in all their parts higher—as, in course of time, the cañon-bed becomes filled to higher planes by the gravels and boulders which are brought by its floods.

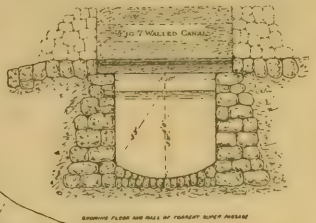
For instance; it will be readily seen, from the section (Fig. 6, Plate VIII) that the dam can be raised as required by building over it successive layers of boulders, laid in cement. The piers of the headworks are planned to admit of raising indefinitely, and other parts are equally susceptible of raising or being built up without excessive cost or much change in other respects. The writer hopes at a future day to present an account of the completed construction and operation of these diversion works, and to submit the plans in detail.

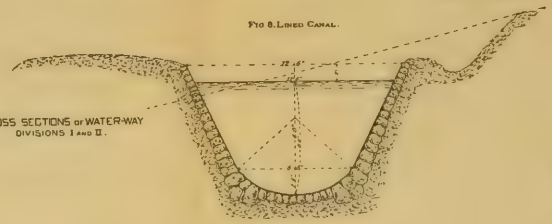
Expenditure at Headworks.—The work done at this heading and its cost was substantially as follows :

First.—The distinctly temporary work. A diversion dam of cobbles, boulders and gravel—about 110 cu. yds. in volume ; a rough rubble heading work, holding a wooden gateway 5 x 5 ft.; thence a semi-circular-formed ditch 7 ft. wide, and paved with boulders and

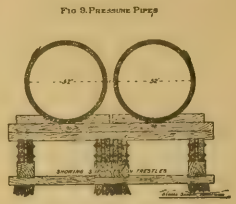


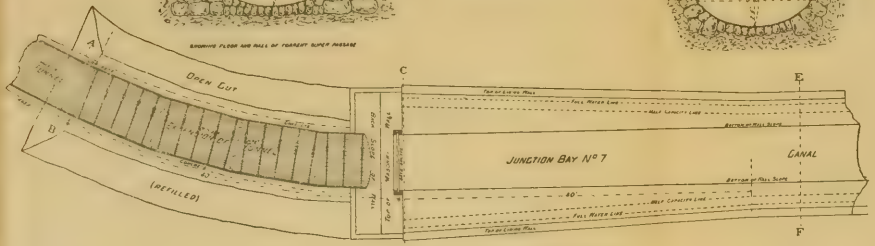




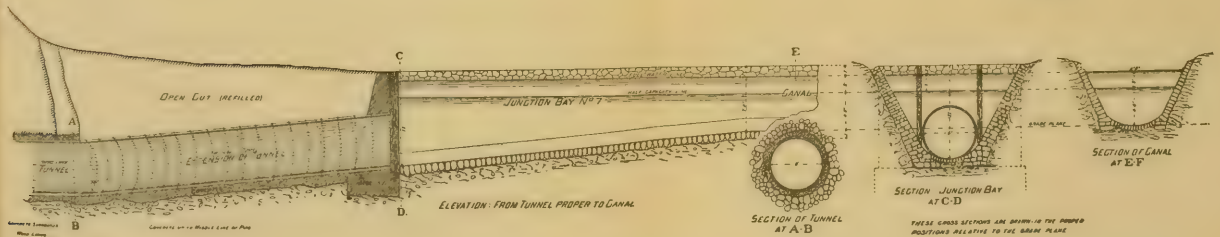


CROSS SECTIONS OF WATER-WAY
DIVISIONS I AND II.





PLAN AND SECTIONS
JUNCTION BAY Nº 7
AND
EXTENSION OF WOOD-LINED TUNNEL
DIVISION II
FIG. 10.


OPEN CUT (REFILLED)
JUNCTION BAY Nº 7
CANAL
ELEVATION - FROM TUNNEL PROPER TO CANAL
SECTION OF TUNNEL AT A-B
SECTION JUNCTION BAY AT C-D
SECTION OF CANAL AT E-F
THESE CROSS SECTIONS ARE DRAWN TO THE PROPER POSITIONS RELATIVE TO THE GRADE PLANE

effect their driving and lining where necessary by the time it was hoped to have the balance of the work done—namely, before the company's water exchange contract with the Mill Creek zanja owners ran out. And thus the contractors' force was on the ground before the final location was finished over the route covering the tunnel sites.

Under the specifications the contractor was to do all the work, furnish all materials, tools and outfit required therefor, except what lumber might prove necessary for lagging and timbering. This the irrigation company was to furnish and deliver at the nearest point it could be wagoned to without constructing roads specially for the purpose. But little timbering was anticipated, and this expectation was very nearly realized.

All the tunnels were to be uniform in cross-section; but provision was made for such variation, in excavated section, as timbering would make necessary. The excavation to the neat line, through hard rock, not requiring timbering, was to be 6 ft. 3 ins. wide and 7 ft. 6 ins. high, inclusive of the arched top and invert, in the form shown by Fig. 1, Plate IX. These dimensions practically make necessary about 1.5 cu. yds. of excavation, as a minimum, to the linear foot of tunnel. Through material requiring timbering the form and dimensions were to be as shown by Fig. 2, and these necessitate about 1.9 cu. yds. of excavation per linear foot.

The specifications were explicit and stringent as to exercise of care not to unduly shatter materials driven through, because it was desired, wherever possible, to avoid timbering or otherwise supporting the roofs; and experience in California is to the point that tunnel contractors will "blow the hill to pieces" in order to cheapen their work, if they are not held in check. Moreover, seeing that the tunnels were certainly to be lined for the waterway, there was a penalty provided for excess of excavation behind the neat line, beyond a 6-in. average limit for any 10 ft. of tunnel, as well as for bad results, in sides or roof, due to excessive use of explosives. A principal feature of this penalty was a charge against the contractor of 40 cents per cubic foot of concrete which it would take to fill space worked out, or badly shattered, in excess of the limitation.

The specified time-limit, to cover all the tunnel work, was based on one day for each 12 ft. in length of the longest tunnel to be driven, with an additional 12 days for each approach to that tunnel. In the

PLATE X.
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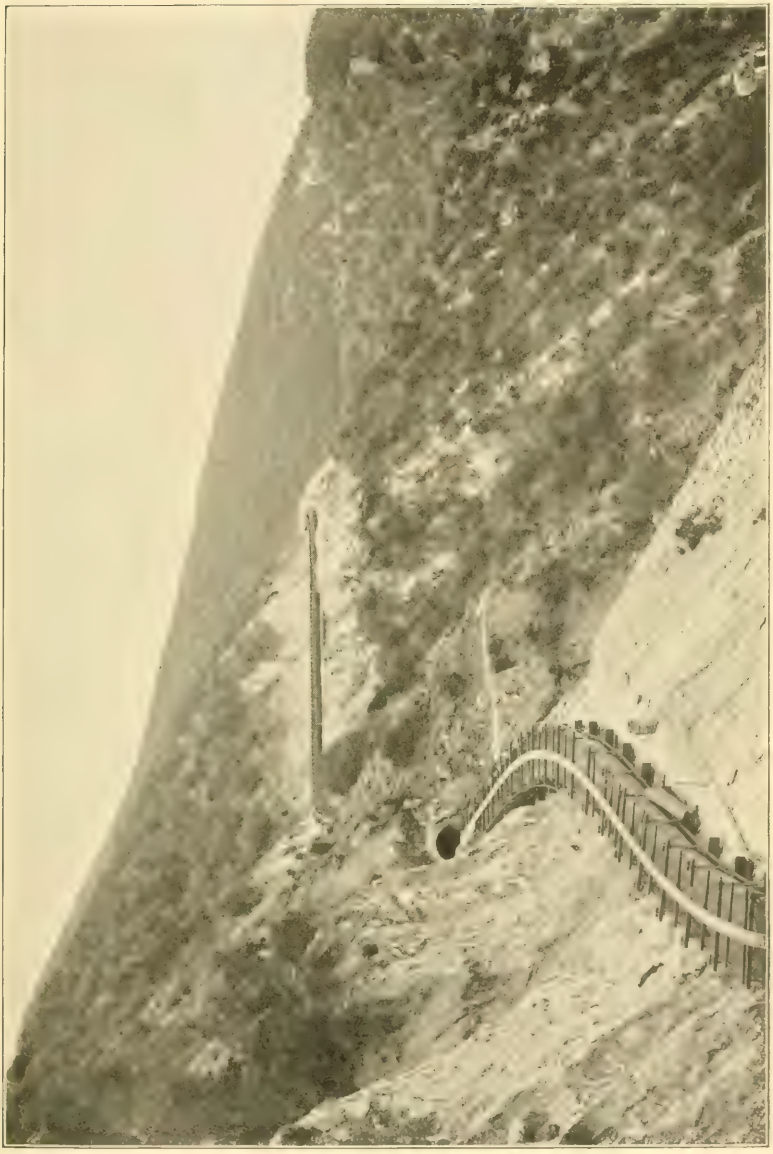
HALL ON SANTA ANA CANAL.



contract this limit was extended about 10 days and fixed for a definite date. Payments of 75% were to be made on progress estimated every two weeks, and the balance was to be paid 35 days after completion and acceptance of the work as a whole.

In consideration of all the work being awarded them, the contractors agreed to throw off $1 000 from the total amount which would in the end be due them. One hundred dollars per day was the penalty forfeiture for the time taken over the limit, to effect completion. As it turned out, this latter provision was not enforced, because the irrigation company itself was delinquent in making its payments, and the tunnels could not have been used had they been finished on time, seeing that other parts of the work were even in greater degree behind hand. The full completion was delayed more than a month, but the tunnels, severally, were ready soon enough for the company's occupation and finish work. That which took the longest time was not the longest tunnel. The longest, tunnel No. 8, was finished within the limit, but tunnel No. 5, which was 184 ft. or 15½ days shorter, took nearly two months longer. Fortunately, there was no necessity for either timbering or lining, for immediate use, any portion of the waterway of this tunnel No. 5, except at and very near the south portal, as there was of tunnel No. 8. Most of the tunnels were sublet, the main contractor agreeing to furnish the plant, and, generally, a certain amount of powder and fuse, and to do the blacksmithing, and put in and operate ventilating apparatus where necessary, and the subcontractors doing the driving and all else.

The circumstance of letting by contract in with the tunnels the excavation of approaches thereto, and at the high rate of $1 75 per cubic yard, was unfortunate, not only as having materially increased the total cost by reason of the excess of this rate over what the work could have been done for by the day, in connection with the flume-bench grading, but as resulting in complication of the construction cost accounts.

For instance, four short tunnels let in the contract were abandoned and open cuts substituted for them, after more or less work had been done on their approaches. Could the engineers have had the advantage of working a day force for a couple of weeks prior to drawing the specifications in examining the points which these tunnels were expected to pierce, they would not have been projected, and the neces-

sity would never have arisen for crediting the tunnel account and debiting the flume-bench account with the amounts due the tunnel contractor for approach work to them, and for making certain other adjustments to get at the flume-bench cost.

On a work of this character, where a tunnel is in rock sufficiently hard to stand without roof support, and not subject to weathering, and if the face is well cleared and stripped above the opening, in the climate of Southern California portal walls and arches of masonry or other expensive construction can usually be omitted, and especially for tunnels through points where no surface-water channel comes down over them. The ends of nearly all of the tunnels in division I, Santa Ana Canal, were thus favorably situated.

In such cases the connection between flume and tunnel was made by carrying the former about 18 ins. to 2 ft. inside the solid tunnel mouth, opened out to leave a space 6 ins. to 1 ft. all around the flume shell, and then ramming concrete into this space, as elsewhere explained. Simple joinings of this class were charged against the tunnel account as "connections."

In cases where special portal work was necessary as finish to full lining and arched roof work, or to support the tunnel face, such work was charged against the tunnel as its portal. But where masonry tunnel portals were built as part of other constructions having a function separate from the tunnel, and where the masonry frontage was not necessary for the tunnel as such, the portal work was charged to the other structure. This was the case at the upper ends of tunnels Nos. 3, 4 and 6, at each of which points a masonry wasteway bay is located. These tunnel portals were built as gateways, to be closed when water is turned out of the wasteways immediately above; the flume connections were made at the other ends of the wasteway bays and as parts of those structures. At each end of tunnel No. 8 are special pipe junction bays, built with and including the tunnel portals, so there are no connections or portal charges, as such, here. At the intake of tunnel No. 1, the portal is counted as part of the headworks of the canal, and at its lower end all, except a small amount of work to protect from overhead débris, was charged to the walled canal which there makes close connection with the tunnel mouth.

As tending the better to adjust costs to what they ought to be, the $1 000 rebate to be taken from the total of the tunnel contract work has

been applied by the writer wholly in reducing the cost of the approach work, *pro rata*, wherever executed, and this adjustment reduced the cost of such work from $1 75 to $1 41 per cubic yard.

On Plate IX, Fig. 1 shows the form and dimensions of excavation and lining with concrete adopted for tunnels in hard rock, which would not for any reason require overhead timbering and arching, and which would have to be lined for purposes of the waterway only.

Fig. 2 shows, in section, the form, dimensions, temporary timbering and subsequent concrete finish for bottom and sides adopted for tunnels in ground requiring full timbering and lagging as driven. This section was intended to be finished for permanent work, as might be expedient in conformity with one or the other of the two following. According to circumstances, also, it was expected that the space behind the lagging, and consequent thickness of final finish of this section, would vary much, and such has proved to be the fact. The drawing shows the very minimum space and thickness possible.

Fig. 3 shows the section, dimensions and finish adopted for tunnels in rock which would stand without timbering at first, but which would require lining to support the walls, and in whose roofs some settlement and pressure might be anticipated. According to circumstances, the concrete walls might be somewhat lighter, and under others they were expected to be somewhat heavier than shown. The brick arch of this section, backed with concrete, is intended also for application in the final finish of section II in cases where roof pressure might be expected.

Fig. 4 shows the form and dimensions and roof finish adopted for tunnel in material that would not require timbering as driven, but would require subsequent lining for wall support and to prevent droppings from the roof, due to air slaking. The remark made about thickness of walls for section III applies equally to this one. This section, IV, was proposed as a substitute for section III, where allowable, for the period of the life of one roofing, at least, because much cheaper. As will be observed, the roof in section II is lower than in sections III and IV. This was thus purposely designed, to admit of trimming in putting in final work.

The quantity of concrete required for any of these linings depended, of course, very much on the extent to which excavation was actually carried. Except where more work might be necessary to preserve the tunnel, it was the intention at first to bring the permanent lining only

so high on the sides as would afford waterway for the half-capacity finish elsewhere spoken of. But in tunnel No. 8, for want of time and means, the concrete finish was not brought even to that height, as will be shown.

Tunnel No. 1.—Length, 216 ft.; a medium hard rock of granitic appearance, but not a true granite, disposed in heavy strata, dipping about 45° and with a diagonal strike across line of work; occasional seams less than 1 ft. thick, of much softer material, and with more the appearance of granite, subject to air slaking and certainly liable to erosion by strong water currents and disintegration therein; occasional very hard spots and nodules, making uneven and hard drilling, worked out irregularly in blocks and masses; difficulty in holding excavation, within limits, to lines and grade; no water encountered; no timbering necessary, except temporary at south portal; some material, especially near bottom, too soft to trust water on; hence, necessary to put in lining before using, although most of the material would stand water indefinitely.

Cost.—The contract price for driving this tunnel was $9 per linear foot; or, total cost, $1 944. From this amount $36 was deducted as a penalty for 90 cu. ft. of excessive excavation, thus reducing the amount paid to $1 908, or $8 83 per foot. Adding $60 12 expended in day labor trimming and final clearing preparatory to actual lining work, and the total cost to the company, before lining, was $1 968 12, or $9 11 per linear foot. The work was understood to have been sublet at $6 50 per linear foot, the main contractor, in addition, supplying tools and doing the blacksmithing. But, owing to slow progress on part of the subcontractor, the main contractors took it out of his hands and finished it under pressure for time, and, as they claim, without profit.

The waterway is completely lined with concrete, as per Fig. 1, Plate IX, at a total cost of $637 70, or $2 95 per linear foot. Total cost of tunnel, $2 605 82; $12 60 per foot. As already explained, there were no portal or connection charges against this tunnel. Details of cost are given elsewhere.

Tunnel No. 2.—Length, 208 ft.; a medium hard granitic rock, much like a true granite, but with many cleavage planes; no distinct stratification; occasional hard nodules and masses; some soft and apparently disintegrating layers, subject to air slaking, and, in a small degree, liable to erosion and disintegrating action of water; a few seams

which may extend and cause leakage; worked out in small masses; no difficulty in keeping within limit to line and grade; no water encountered; no timbering required; not necessary to line for immediate use; will require lining before more than one-fourth capacity is taken through, and within a couple of years; contract price, $8 50; supposed to have been sublet for about $6 50 per linear foot.

This tunnel was virtually a gallery driven 10 to 20 ft. within the cliff's face. At one point where there was a deep gash in the precipice, about 8 ft. in length of side was blown out and a slide came down from overhead. Repairing this, about 7.5 cu. yds. of masonry wall, together with some concrete and plaster work, and a roofing protection of timbers, was put in. There was no lining work done in this tunnel except just enough to well connect its waterway at each end with the flumes section. There was no work distinctly in the nature of portal masonry.

Cost.—The cost of driving, with $5 50 for clearing and trimming and cleaning, brought the total cost of tunnel to $1 773 50; per foot, $8 52. Flume connections, $16; wall, overhead protection, etc., $87 18, with some concrete used in lining and work at portals, brought total to $1 896 68, or $9 11 per linear foot.

Tunnel No. 3.—Length, 236 ft.; practically the same materials and conditions as tunnel No. 2, but somewhat more homogeneous; contract price, $8 75; supposed to have been sublet at between $6 and $7 per linear foot.

Cost.—This tunnel was not lined, but some patchwork was done with concrete and plaster to stop seams which might leak and waste water. A dry rock wall was built at one of the portals at a cost of $42, which with one of the flume connections, $8 50, the concrete patchwork and the usual amount of lining to join the flume waterway, brought the total cost to $2 144 53, or $9 09 per linear foot. Of this, $2 070 was for driving and clearance, $8 77 per linear foot. The cost of work and flume connection at the north portal of this tunnel was charged to wasteway No. 2, there located.

Tunnel No. 4.—Length, 54 ft.; moderately soft but firm and uniform; very near a true granite; not in layers; evidently subject to air slaking; probably but little subject to action of water currents; worked out very regularly and true to lines and grades; no water encountered; no timbering necessary; no necessity for lining for im-

mediate use, but will have to be lined within a year or two, before exposure to air takes effect ; contract price, $8 75 ; supposed to have been sublet at $6 per linear foot.

Except as a preservation from air slaking there would be no necessity for lining this tunnel with concrete. It cut out quite smooth and true. If the work had been on force account the section might have been diminished and a heavy plaster finish applied directly on the face of the rock. A masonry portal and gate at upper end of this tunnel is part of and charged to wasteway No. 3, next above it.

Cost.—Driving, $472 50; with clearance, $2 30; flume connections, $7 80; work about portal, $11, brought the total to $494 11 ; $9 15 per foot, as completed for present use ; $8 79 as driven and cleared.

Tunnel No. 5.—Length, 1 410 ft. A dark, close-grained solid granite; very refractory to drill and hard to blast; worked out in large masses, very irregularly, leaving a rough and uneven face all around; much difficulty in holding excavation within limit to lines and grade; water encountered in both headings, and drips from overhead gave much trouble; no timbering necessary, except at south portal, where is a slide from mountain overhead; no necessity for lining for preservation, except at locality above mentioned; contract price, $9 74; supposed to have been sublet at about $6 50; subcontractor forfeited contract; main contractor finished work.

The rock was hardest near the south end, where the average daily progress was 3.2 ft. against 4.7 ft. for the north end face, a total average of 7.9 ft. per day. Steam drills tried in the south face, but heat from exhaust and difficulty of carrying steam so far with the plant at hand rendered them impracticable. Ventilation at first effected by stove draft, then hand blowers, and then steam-power blowers. Portals both in deep ravines; hence, less circulation of air about portals and more necessity for artificial ventilation in tunnel.

Cost.—Driving contract, $13 733 40, less $39 for insufficient trimming, and $433 90 penalty for excessive excavation; balance, $13 260 50; $9 40 per linear foot. The amount actually expended in force work for clearance did not materially change this rate. Some timbering and concrete lining was put in at the south end at a total cost of $195 43, which, with brick, etc., portal work at same end, $40, and flume connections, $18, brought total to $13 532 43, or $9 59$\frac{7}{10}$ per running foot.

Tunnel No. 6.—Length, 58 ft. A soft, shattered shale in strata, dipping across line of work; worked out irregularly; difficulty in keeping within limits to line and grade; no water encountered; overhead timbering not immediately necessary to prevent effect of air slaking; contract price, $8 75; supposed to have been sublet; rate unknown.

This tunnel was lined with concrete to the height for full capacity, and cement plastered, as in the case of tunnel No. 1. The cost of driving, under the contract was $507 50; as cleared ready for lining, $517 50, $8 92 per linear foot; lining, $270 50, $4 66 per linear foot; portal work, additional, $15; flume connection, additional, $5; total $807 65; $13 92 per linear foot. It may be necessary to timber and lag this tunnel overhead in future, to prevent rocks dropping, consequent upon air slaking. But one portal finish and one flume connection was charged to this tunnel, the other being charged to the wasteway there adjoining it in the line, and as part of which it was designed and built.

Tunnel No. 7.—Length, 43 ft. A soft, shattered shale in strata, dipping across line of work; worked out irregularly; difficulty in keeping to lines and grades; no water encountered; timbering necessary in places; lining and arching immediately necessary for every good reason; contract price, $8 75; supposed to have been sublet; rate unknown.

This tunnel was lined completely, as illustrated by Fig. 3, Plate IX. Concrete invert and walls to the full-water finish; a brick in cement arch overhead, and the whole finished in cement plaster. The portals were simply finished in brickwork (see Fig. 1, Plate XI).

Cost.—Driving, $376 25, and clearance, $19—$395 25—$9 19 per foot; lining, $437 94, $10 18 per linear foot; portal finish, additional, $30; connection, $10; dry masonry walls, $71 75; total, $944 94; $21 94 per linear foot, the most expensive part of the entire aqueduct. This high cost is very largely due to the inconvenience of subdelivery to the site of the work, and to the large proportion of labor waste at the time construction was here in progress.

Tunnel No. 8.—Length, 1 594 ft.; south end, 700 ft., in soft marly shale, requiring timbering; occasional seams bearing water, causing sliding ground and rock caving, and necessitating close and immediate lagging; some serious trouble from this cause. Balance of tunnel in soft granitic rock, but apparently not true granite; some liability to

air slaking and washing by water; worked out much more regularly than the south 700 ft. ; timbering not necessary. Immediate lining necessary throughout, as high as water is to be carried. Contract price, $9 74 per linear foot ; supposed to have been sublet at $6 per linear foot.

The conditions for working this were, on the whole, favorable for so long a tunnel, notwithstanding the difficulty had with water and the trouble of timbering. The average daily progress was 6 ft. in the north end heading, and 7 ft. in the south end. Ventilation was effected by stove drafts only, as both ends of tunnel open into big cañons where there was free circulation of air past the portals.

The timbering was done for the 700 ft. in accordance with the plan shown in section by Fig. 2, Plate IX. The concrete lining was put in for the invert and walls 1 ft. high, and plastered, in accordance with the same plan.

Cost.—Driving, contract, $15 525 56 ; clearing and trimming during course of lining, force, $119 87 ; total excavation, $15 645 43. Lining, total, $3 131 38 ; including concrete, $2 317 78 ; plaster, $467 60 ; tile drainage, $36 ; cost and delivery of timber and lagging lumber used in driving, $310. Rates per foot of tunnel : driving and trimming, $9 13 ; lining, total, $1 95 ; concrete, $1 45 ; plaster, 29 cents ; concrete and plaster, $1 74.

Tunnel No. 9.—Tunnel No. 9, through Morton Ridge, 509.8 ft., is in a mass of cemented boulders and gravel. Firm and generally very hard when first bored, this material is subject to slow air slaking as well as to more rapid disintegration under the influence of water and the moisture over it in a tunnel. Farther on in the general route of the projected canal, a number of narrow, sharp, but long ridges—saw-tooth spurs of the San Timoteo range of hills, similar in general formation to Morton Ridge, but whose substance is much more easily pierced in tunneling—are encountered. If an efficient and durable lining can be put into such tunnels within a certain low limit of cost, considering the very cheap rate at which the ridges in question can by special means be pierced, there would be good reasons for adopting a location whereon, in construction, this character of work would be given prominence. The lining of tunnel No. 9 was intended, therefore, not as a novelty and study of economy for that one bore alone, but as an experience, the results of which might govern the placing and building of several miles of the line beyond.

FIG 1

FIG. 2.

Brick and cement concrete linings in any form of cross-section, but sufficiently thick to insure against dropping of large boulders or masses of the cemented gravel which are liable to become detached in this peculiar formation, would be too expensive for the work. Experience on this company's older works has also shown that asphalt or asphalt concrete cannot be depended on under these circumstances as a tunnel lining when put in thin enough to make any material saving in cost under that of cement concrete or of brick. The ordinary wood linings of tunnels would very soon rot out. It appears that something new as a lining had to be evolved, or the idea of location through the sawtooth spurs be given up, if another advantageous route could be found.

As completed, tunnel No. 9 is a smooth-finished tube, 6 ft. inside diameter. The lining is made of 3-in. thick redwood staves, which have been firmly pressed into place and are solidly held within a thin shell formed by ramming concrete as a backing into the space between the staves and the face of the tunnel bore. It is in effect a wooden stave pipe, not banded with metal, but held just as tightly, for all practical purposes where there is scarcely any head of water pressure, by being pressed in concrete through the solid hill. The wood and concrete lining thus formed is more than amply strong to withstand any pressure from without that will be brought upon it in Morton Ridge or any similar location. Properly put in, it will not leak; so there will be no danger from the effect of wetting the material through which it is laid. And to preserve the wood, tunnel No. 9 is located more than its diameter below grade, so that, no matter how little water may be running in the aqueduct, the tunnel must remain full and the staves be always thoroughly soaked.

Although, owing to reasons elsewhere explained, the cost of this tunnel as a whole was not low, the experience has shown the feasibility and advantage of lining tunnels through material having the general character of cemented gravel, marl, compact earth, soft but firm stone, etc., by the general method here experimented with, and at costs so low as to command attention for works of this class. And it is believed that the location of such tunnels so that they will always be full of water and under very light hydrostatic pressure establishes conditions such that the wooden lining will last as well as any other, within practicable limits of cost for irrigation works.

There was nothing novel in the excavation of tunnel No. 9, and the means for making such bores in softer materials, which the experience suggested and showed the feasibility and desirability of, will properly find description only after more extended application.

The lining was put in as follows: The concrete backing for about one-sixth of the circumference was first laid in the bottom of the tunnel bore and rammed to grade and form for a considerable length in advance of other work. In a layer of wet mortar spread over this bed staves were laid, and on top of them the tunnel-centering forms were set. These bottom staves were then clamped together, and, at the same time, the tunnel forms forced down on them. When these bottom staves for several lengths were thus brought to their position and bearings, and the forms centered and tightly braced in position over and upon them, the lining was laid up around the sides. One stave at a time, on the two sides simultaneously, was placed and firmly pressed and clamped into bearing against the next stave below it and against the outside of the centering frames, and immediately the concrete was shoveled and rammed into the space behind it. Thus the lining was brought up and around until it came to placing the last three staves overhead. Two of these, one on each side—in form tapering lengthwise, so as to leave remaining open between them a space, and tapering several inches in the length of the stave—were then placed. After concrete had been tamped over these last staves on each side, the opening between them was closed by driving endways into it pieces of stave, each 1 ft. long, and duly tapering, over each of which the concrete was rammed, longitudinally, before the next one was driven.

This lining was built in lengths from 8 to 14 ft. each, as the lumber ran. The staves of the succeeding lengths were "broken-jointed" together, with an end lap of 4 ins., and the end joints were made, between each two abutting staves, with a metal tongue taken into a saw kerf in the staves' ends, as in recent wooden pipe construction practice. The staves were a little less than 8 ins. wide, somewhat less than 3 ins. thick, with the edges milled to radial lines of the circle in which built, and with a ¼-in. bead on each edge, one-third the thickness from one side.

The tunnel is straight for 400 ft. of length; then it curves to the left for 69.8 ft., on a radius of 91.7 ft.; and thence the wooden shell

was built as a banded pipe in an open cut, and in continuation of the curve for 40 ft. further, where it ends in a concrete portal wall. The space in the cut around and over the built pipe having been refilled and made solid, the whole has a uniform tunnel-like effect.

By referring to the plates the application of the following about some details of this tunnel work will be made clearer. Plate IX, Fig. 10, explains the relation of the parts to each other and to the hydraulic grade, at the tunnel's lower end. Figures on Plate VIII relate to the arrangement at the upper end.

The down-stream end of the tunnel proper—469.8 ft. from its intake—is 80 ft. from the point of commencement in normal section and on grade of the lined canal, and is 7 ft. below it in grade elevation. The grade plane between these two points rises evenly—that is, 7 ft. in 80, or at the rate of 8.75 per cent. Of this distance, 40 ft. is the tunnel extension, made in open cut and afterwards covered in as above explained, and 40 ft. is constructed as a backwards extension of the lined canal—widening on top as due to side slope, and deepening on the 8.75% grade—to a junction with the tunnel portal wall.

In the opposite direction, from its down-stream end, the tunnel proper falls 2 ft., so that at its up-stream end its grade plane is 9 ft. below that of the commencement of the lined canal, 549.8 ft. down the line from it. Thus the entire tunnel proper will be under a pressure head of between 1 and 3 ft. at its top plane when there is any water whatever running in the aqueduct, and between 7.3 and 9.3 ft. when the full 240 second-feet are flowing, besides the additional head which its own hydraulic gradient will subject it to.

At its up-stream end it flares, in 16 ft. of length, to an oval having horizontal and vertical axes of 114 and 72 ins., respectively. The purpose of this flare was to receive, with least disturbance of current, the waters from two 52-in. pressure pipes, laid side by side, and 6 ins. apart, and which will form the completed aqueduct across Morton Cañon. This junction is referred to more in detail elsewhere. Thus, the Morton Ridge tunnel is, in effect, a continuation of the Morton Cañon pressure pipes united.

Provision is made by a gateway at the down-stream portal of the tunnel to close it, from below up, sufficiently to keep the wood lining of the down-stream extension, where it rises above canal bottom grade, always submerged, no matter how little water be running in the

aqueduct, if so desired. And at the up-stream end provision is made for emptying it backward into Morton Cañon for the annual clearance.

The up-stream oval flare was built the same as the cylindrical lining, inside of its excavation, made to due form and dimensions. Staves were tapered to suit; pressed into place, one by one, on each side; backed up with concrete, rammed behind each as placed, and the closure was made overhead with a taper stave, cut into 2-ft. lengths, and driven as wedges, successively, after concrete had been rammed lengthways, over each preceding one. The penstock making the junction between the pipes' ends and the flared tunnel mouth, and occupying 4 ft. in clear length in the line, sets close against the tunnel portal, receiving the tunnel lining staves in one side and the pipe staves in the opposite side, in the relative position shown by the figures on Plate VIII, Fig. 4.

In making the curve and breaks in grade at the south end of the tunnel proper and in the open-cut part of the work, 10-ft. staves were uniformly used and sawed to allow for curvature angle in each 10-ft. bent or length, the longest stave in each length, on the outside of the curve, being 10 ft., and the balance shorter in due sequence; but the end joints were all made just as in the tunnel proper. In the open cut there were four $\frac{3}{4}$-in. round steel bands put on each 10-ft. length, as built in place, just to hold it tightly in form as a pipe, until the concrete could be rammed against it and the back filling be made after this latter had set. This part of the wood lining had a thicker bedding of concrete, and this bedding was brought up nearly to the half-depth line on each side.

About the first 50 feet of this tunnel lining was not put in to the writer's satisfaction. It was feared that some leak might develop that would in time soften the ground around it, so all the seams of this piece were opened with a spreading iron and calked with oakum, as were those also of the oval flare piece. And wherever, by thorough search throughout the entire work, a bit of seam could be found that did not appear by trial with a thin knife edge to be under pressure, it, too, was spread open and calked.

But the writer does not now think that this precaution was really necessary. These staves were quite well seasoned when put in, and their swelling would much more than have closed any open seam that

was found. Moreover, the cement paste of the concrete, by the process of ramming, was forced into the back part of seams where at all open, and this alone would insure a water-tight structure, even though the concrete itself might happen at some point to be specially thin immediately outside of a poorly laid portion of the stave lining. When completed, this tunnel had a most favorable appearance as a water conduit, and has since done good service without apparent leakage, except immediately at the penstock junction, for a short time at first; but this was soon stopped.

Several specially arranged steel centering frames and appliances for, and methods of, pressing and holding the staves into place were devised and used during the course of the work. The writer hopes to present this particular part of the subject at some future time more worthily than he can at present.

With proper appliances, and with due system in the work and close engineering supervision on the part of some one looking to the best outcome, the writer believes that most excellent results are to be had, and great savings effected, by this method of tunnel lining for water carriage through materials such as have been herein spoken of.

It is, in effect, lining a tunnel with a thin layer of concrete rammed behind mould boards, and then leaving the mould boards in place as part of the lining. In this connection, attention is asked to the following points: That to line a tunnel with concrete at all the labor of handling the centers and mould boards into place has to be performed, at any rate; that when this work is systematized and performed with special labor and time-saving appliances it can be materially diminished in cost and a far better job be effected; that in this manner the mould boards can be put in to stay with no more labor than for the ordinary temporary purpose; that if we leave the mould boards in we save the expense of handling them out; that the lumber part of the lining thus placed will generally cost, at the tunnel mouth, less per unit of volume than the concrete part; that it can be taken in and put into the work at less cost per unit of volume than can the concrete; that concrete is the cheapest efficient lining heretofore used (in Southern California, at least) for similar purposes; that this wooden in-lining seems to correct the defects and failings of thin concrete linings such as have here been attempted in tunnels for similar purposes, and to better guard against rupture by earthquakes; that the planed wooden

face diminishes friction, and materially increases capacity. Then, if the wood is not to decay, and if the lining is not to be crushed, it would seem that the device and method have advantages which make them worthy of attention.

It must be remembered, however, that this tunnel lining is spoken of only for the purpose of water carriage, and for localities where there is to be no ground movement, and, consequently, no great pressure brought upon it; because in such localities it can be put in very thin and very rapidly and very cheaply. Where it is continuously kept submerged—wood between cement and water—it would seem that a long life awaits it. Will not wood under these conditions outlast that in a pipe covered in earth? Is not the thorough coating of cement it receives on its outside, from the effect of ramming the surrounding concrete, and the casing of concrete itself, a preservative against the earth influence which is sure to shorten the lives of wooden pipes laid under ground, at least in many soils? As to the lasting qualities of such tunnel linings against the wear of sands, the same remarks apply as are elsewhere offered on this point with respect to pipes.

Cost.—The 469.8 ft. of tunnel proper cost $5 939 27; of which $2 129 75 was for driving and trimming, $1 798 85 for concrete backing, and $2 010 67 for wood lining; or, $3 809 52 for lining complete. Rates per foot of tunnel: For driving and trimming, $4 53; for the concrete backing, $3 82; for the wood lining, $4 28; for lining complete, $8 11; for the tunnel complete, $12 64.

The 40 ft. of extension cost $353 80; of which $103 was for excavation and back fill, $60 50 for concrete, $190 30 for the wooden pipes, banded, or $250 80 total for the pipe and concrete setting. Rates per foot of extension: For excavation and back fill, $2 57; for the concrete, $1 51; for the wooden pipe, $4 76; for the pipe and setting, $6 27; for the extension complete, $8 84. The tunnel and extension, 509.8 ft. in length, cost $6 293 07—average of $12 34 per foot of line covered.

Walled Canal.

The piece of walled canal next in the aqueduct to tunnel No. 1, shown in section by Fig. 7, Plate IX, is 152 ft. long. Of the total length, 60 ft. in the clear are covered with two layers of 2-in. redwood plank for the torrent superpassage, as illustrated by the figure above

referred to; and masonry walls, from the point of rock on either side of the ravine, serve as training walls to the torrent to and across the passage.

These walls, as also those of the canal itself, are built of heavy river-wash granite boulders, well bedded and laid in lime mortar with some cement. The canal invert was paved, chinked, sanded and grouted as hereinafter described for the bottom of the lined canal. And the entire inside of the waterway and tops of the walls were plastered with cement mortar. This plaster for the invert was the same as elsewhere described for such bottom finish; for the sides and caps of the walls it was 1 to 4 of cement and sand.

Cost.—In addition to 171 cu. yds. of sand, gravel and rock in the approach to tunnel No. 1, which was taken out under the tunnel contract at a cost of $241 11, or, $1 41 per cubic yard, but is herein charged to this piece of canal, there were moved for it by day labor 305 cu. yds. of sand, gravel and débris at a cost of $64, or 21 cents per cubic yard. Of this material, 110 cu. yds. were afterwards back filled and shaped into place against the walls at a cost of $12 10, or 12 cents per cubic yard; and 23 cu. yds. of heavy river boulders were hauled and placed for the paving of the superpassage channel, at a cost of $25 53, or $1 11 per cubic yard.

The masonry, laid in lime and cement mortar, measured 158 cu. yds., and cost $713 87, or $4 52 per cubic yard; the canal paving, sanding, etc., cost $22 90 for the 905 sq. ft., or 2.5 cents per square foot; 2 130 sq. ft. of cement mortar plaster were put on at a cost of $96 50, or 4.5 cents per square foot; and 20 cu. ft. of concrete, at the flume junction, cost $6 72, or 33.5 cents per cubic foot. These charges, with the cost of the woodwork of the superpassage channel, $63 50, brought the total cost of this structure to $1 246 23, of which $1 005 12 was originally charged to it, and $241 11 has been transferred from the tunnel account. This structure, like tunnel No. 1, is complete for the full duty of passing 240 second-feet of water.

The Flumes.

The flumes placed in these works are believed to be entirely novel in design and are thought to constitute a new type and departure in flume building. They are broadly described by the general name given—the stave and binder combination flume—and, substantially,

consist of wooden staves bound and held together in a rounded bottom, straight-side form, by iron and steel ribs and binding rods, acting in conjunction with wooden yokes or ties across the top.

In its simplest form this kind of flume is semi-circular in cross-section, and consists of staves drawn tightly together in that shape and held by binding rods bent to the transverse curve of the bottom, each serving to draw down on the top edges of the upper staves a cross-head or yoke which extends over the top, projects over the sides, and is engaged by the rods. In this primary form, with the staves milled in cross-section to the circle of the desired size—that is, with the outer side rounded to the circumference, and the edges beveled to the radial lines—it is plain that the edgeways compression of the staves not only serves to close the seams and thus render the shell water-tight, but tends to hold it in shape, out against the rods. With the top edges braced apart by the stiff yoke or cross-head, there can be no tendency for this shell to buckle inwards. It is essentially half of a wooden pipe.

Going a step further in the development of this flume, the sides, formed of broader boards, are carried vertically—in the line of the tangents from the ends of the bottom half-circle—to the height desired, and the yokes are put across, over the tops of the side boards, and the binding rods carried up to them. Then, applying the binding compression edgeways on the shell, at the top of the side boards, produces a tendency for these to buckle inwards; and, moreover, unless the shell is of small size, or staves proportionally thick, the whole structure would lack necessary stiffness and stability. To remedy this, stiff ribs, made also to serve as binders, are introduced at intervals in the length of the structure; and out to these the side boards are firmly held by a special device, which prevents their inward buckling or warping, while at the same time they and the staves are permitted to move edgeways around within the ribs, so as to admit of the necessary binding or loosening of the shell. Thus, the leading general idea is to have a flume shell compressible and adjustable at will within a framework, in order that it may be kept water-tight under all conditions and circumstances.*

* This flume, in its primary form, was separately and independently invented by Guy Sterling, C. E., of North Yakima, Wash., and by the writer. The designs for the Santa Ana work are all the independent and original productions of the writer.

PLATE XII.
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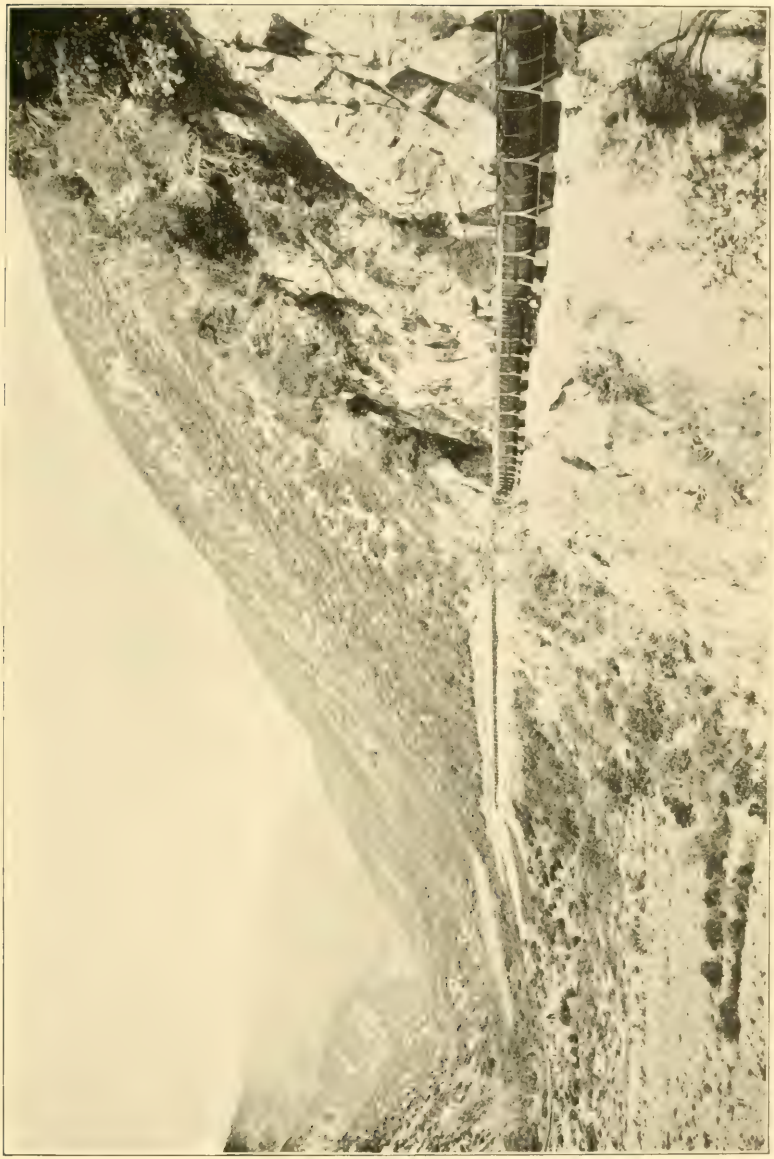

Different forms which may be given a flume of this character, and variations in construction details, will suggest themselves to the engineer. This paper presents the experience with the constructed examples of the Santa Ana Canal only. In section, these flumes have an oval bottom and vertical sides; are 5½ ft. wide inside; and, as designed for full completion, are 5½ ft. deep below the top of the side boards, and are intended to carry 5 ft. depth of water. The exceptions to these general dimensions are in flumes of division II, which, for reasons given, are planned an additional foot in depth.

The oval was adopted for the bottom form in preference to the half circle merely to give a flatter and broader seat to the ribs in the bolsters or sills. Considering the additional trouble and labor in manufacture and erection due to the oval over that which would have been given by the half-circle bottom form, it is doubtful whether there was a net advantage gained. For a very materially wider flume shell, say, 20 ft., it is plain that, in order to attain an economical proportioning of the waterway, secure a good seating, limit the expense of bolstering and bracing, and keep down expense of framing, the oval or even a flat bottom form (with rounded corners and straight sides) would be desirable. Or, on the other hand, for a materially narrower flume, say, 3 ft. wide, the semi-circular bottom would, unquestionably, be the simplest and the best.

Referring to Plate XIII, it will be seen that the Santa Ana Canal flumes have a stiff T-iron rib, resting in a wooden bolster or sill every 8 ft., and that between each pair of these ribs are two binding rods, thus making a binder every 2⅔ ft. of length. As finished for present use, the sides in division I are but one board and a cap-piece high, making the waterway 3.8 ft. in depth below the top of the shell. It is intended to carry about 3 ft. depth of water, which on the grades adopted gives a present capacity of 120 second-feet. Raising the sides 2 ft. will double the capacity. The design eminently admits of such initial economy in construction and subsequent enlargement to meet full demand.

The binding rods are of ⅝-in. round mild steel, screw-threaded (without having the ends upset) for 4 ins. at each end. It would have been better practice to use somewhat lighter steel, and to have had the ends upset before threading. The hurry in which these matters were determined and the desire to simplify the work for Cali-

fornia shops, so as to prevent excuses for high bids, was the reason for this omission in the specifications. These rods pass through 3 x 4-in. Oregon pine cross-ties (laid flat), and the nuts screw down on wrought-iron washers large and thick enough to serve as bearing-plates on the wood.

The ribs are of 2¼ x 2¼-in. T iron, weighing 4 lbs. to the linear foot, and machine-bent to the form desired, with the flat flange inwards and the rib of the T outwards of the frame. Thus, the staves have a 2¼-in. flat rest against the ribs. A flat key-eye strap of iron, bolted to the flange of the rib at each end, extends vertically up through the wooden cross-head, and through this eye a steel wedge-shaped key is driven in the plane of the frame (in direction across the flume), and acts as a wedge on the inclined surface of a wedge-shaped bearing plate, which rests on top of the cross-head. This constitutes the means of compression provided on the T ribs, under the ironwork specifications, but for comparison a number of the ribs were afterwards fitted in the company shops with screw-bolt heads, to be operated substantially the same as those of the binding rods. This latter arrangement proved the best, and would have been the cheapest. Here, again, with less haste and time for the manufacture and setting up of a small sample piece of the work before it was all specified, a betterment and an economy would have been effected at one stroke.

For the ribs having straps and wedge keys, the cross-heads are made of two pieces of 2 x 4-in. Oregon pine, held together upon thick cast-iron separators by five screw bolts. Before being put together the two parts of the yokes were cut to admit of the passage of the straps between them, and the greater expense of mortising was thus saved. The plates over them are broad and thick enough to do away with the disadvantage of separating their bearings into two parts. The yokes for the ribs which have screw-bolt heads are of 3 x 4-in. Oregon pine, the same as those used with the round binding rods.

The bolster, or sill, is made of two pieces of 2 x 12-in. Oregon pine (about a tenth of the number were made of redwood), firmly held side by side and ½ in. apart by five screw bolts, each of which has a ½ in. thick cast-iron separator strung on it between the two planks. This bolster sets edgeways upright on its bearings. Into a curved seat, cut in its top edge to a maximum depth of 5 ins., the rib rests for 4 ft. of its

PLATE XIII.
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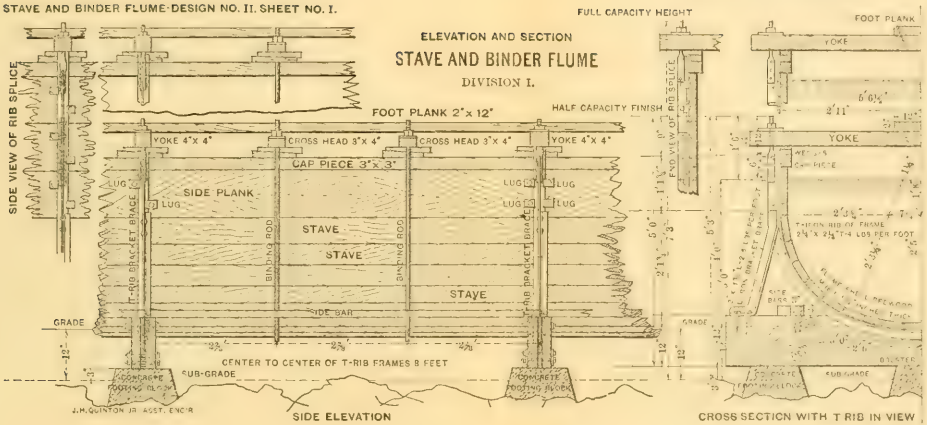
STAVE AND BINDER FLUME-DESIGN NO. II. SHEET NO. I.



length, and with the rib of the iron T sandwiched between the two planks of the bolster.

On each end of the rib is riveted a brace of $1\frac{3}{4}$ x 2-in. L-iron, weighing 2.6 lbs. per linear foot. These bracket braces slope somewhat outward from the vertical below their junction with the rib, to give a broader seat to the iron-work as a whole, and, having their lower ends turned to afford a horizontal footing, are each firmly fastened to the top edge of one part of the bolster by two $\frac{7}{16}$ x 5-in. lag screws. The bolsters, braced ribs and their yokes thus combined are referred to as the frames. In making the bolsters it will be noticed that, whereas it is necessary for the bearing of the bracket braces to carry one part out to a square ending, the other part may be cut diagonally, thus saving 1 ft. length of lumber in cutting to each bolster.

In the Santa Ana Canal flumes the side planks are held out to the ribs by two lug pieces to each plank and rib, each of which is fastened firmly to the plank by a large threaded lag screw, intended not to go through the plank. There being but one lag screw to the lug piece, the latter in casting were provided with two little points which, in screwing them against the planks, are pressed into the wood, thereby preventing turning and consequent cramping against the edge of the rib.

As already stated, the object of the location was to put the flume as much as possible, at reasonable expense, on a full-width bench, where it would not depend on posts or other timber underpinning for support. Accordingly, by far the greater number of the sills rest directly on concrete footings which were made in place on the solid rock of the bench. Where the foundation is of earth or other than rock not likely to crumble, the footings are of redwood blocks on mud sills of the same lumber. Where supported by trestles or girder spans, the sills of the flume rest directly on the stringers. Where supported on posts, without the intervention of a stringer or girder—as was admitted where not more than one sill in a place and for not more than one of its three bearings was in the air—a cast-iron piece acting as a cap for the post and which cannot slip off it, and as a rest for the sill off which it cannot slip, is used.

The iron-work of this flume was furnished all together, by contract, at one price, under specifications and according to plans on which bids were invited. The contractors were the Baker Iron Works, of Los Angeles, Cal., who devised a machine for bending the T-ribs to the

oval form desired, and who turned out very good and uniform work. The T-ribs and binding rods were treated to two coats of red lead, the cast-iron work was immersed in a hot asphalt bath and other parts in hot oil.

As shown by the larger scale section, the flume shell is composed of one center plank $9\frac{3}{4}$ ins. wide on outside, 16 staves, each $5\frac{3}{4}$ ins. outside width, and two side planks, $11\frac{3}{4}$ ins. wide each, on top of which on each side a harder wood cap or edge piece, 2 x 3 or 3 x 3 ins., was afterwards placed as hereafter explained. Being dressed out from lumber of standard dimensions, the actual widths specified and drawn for patterns for planks and staves had to be in each case $\frac{1}{4}$ in. narrow. In like manner, having been dressed down from 2-in. lumber, the planks and staves are but little more than $1\frac{3}{4}$ ins. thick. There being two different curves to fit in the oval, there were two different patterns for the cross-section forms of the staves. Two staves on each side of the center plank are edged to the radii of the larger curve and the balance to those of the smaller curve, notwithstanding the seam between the two forms misses the point of juncture of the two curves by nearly half a stave width.

This lumber was obtained by contract under specifications, and dressed to the forms furnished. It was to have been not only selected, but well seasoned and dried before working. But, as matter of fact, while the quality was good, most of it was quite full of sap or water when delivered. The lumber company had to fill the contract at the season of year when rain prevailed almost every day in the region of their mills, and had been falling throughout the winter. The order being a very large one for one thickness of high-grade stuff, strict compliance with specifications on this point probably could not reasonably be expected. At any rate, the Irrigation Company had to accept very wet lumber for the staves or not get the work done. Nevertheless, these had from two to four months in the very dry climate of Southern California in which to season before they were finally bound in the flume, and yet it was no uncommon circumstance to compress the shell in the process of final cinching, as much as 1 in. on each side, after it had shrunk and been drawn down 1 to 2 ins. on each side in the seasoning.

As will be seen on the larger scale section (Plates XIII and XIV), the staves and boards composing the shell each have an $\frac{1}{8}$-in. bead run in its edge one-third the thickness from one side. The compression, of

PLATE XIV.
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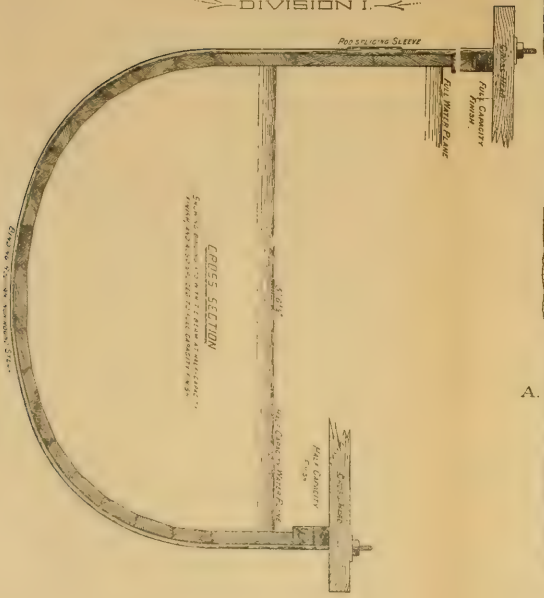
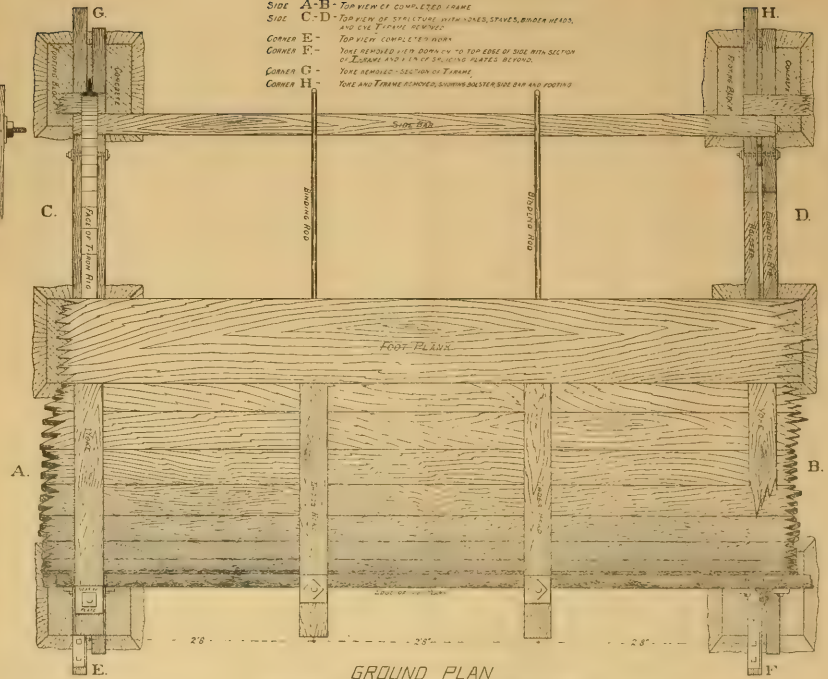
PLAN AND SECTION
STAVE AND BINDER FLUME
DIVISION I.



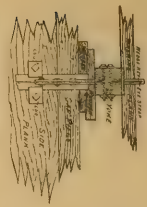
EXPLANATION

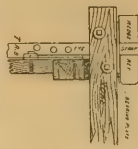
SIDE A-B - TOP VIEW OF COMPLETED FRAME
SIDE C-D - TOP VIEW OF STRUCTURE WITH STAVES, STAVES, BINDER HEADS, AND EYE TIMBER REMOVED
CORNER E - TOP VIEW COMPLETED WORK
CORNER F - YOKE REMOVED WITH DOWN CUT TO TOP EDGE OF SIDE WITH SECTION OF I FRAME AND 2 LINK OF SECOND PLATES BEYOND.
CORNER G - YOKE REMOVED - SECTION OF I FRAME
CORNER H - YOKE AND I FRAME REMOVED, SHOWING SOLSTER, SIDE BAR AND FOOTING

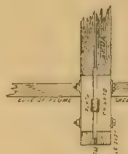


GROUND PLAN

SHOWS UPPER EDGE OF FLUME SHELL WITH WEDGES AND CAP PIECE REMOVED







PIN HEAD AND YOKE ENDS FOR THE MOST PART BUILT IN THE SANTA ANA CANAL FLUMES

course, sunk these beads each into the edge of the abutting stave, thus forming in each longitudinal seam two little tongues and grooves, as it were.

The flume shell was for the most part built in lengths or sections, from rib to rib. Where the alignment is straight, the lengths are 16 ft., covering two bents; and where in curve they are only 8 ft. long, from frame to frame. In tangent, of course, the ends of all planks and staves are square cut, and the butt joints come squarely in the middle of the T-ribs. Where in curve the plank and staves had to be sawed to fit, and it was found that the simple way of fitting and scribing each plank—the carpenters working in pairs, one at each end of the plank—was the most expeditious. These workmen became very expert at what was really a difficult piece of mitre carpentry, and the staves as cut in made very close end joinings. But several weeks of summer sun on the lumber thus lightly cinched in the frames shrunk the redwood lengthways, so as to open the end joints $\frac{1}{8}$ to $\frac{3}{16}$ in., thus to a great extent doing away with the use of the spreading iron preparatory to calking. This calking was done with oakum, on top of which, to a third of the total depth, the seams were payed with hot asphalt.

On some of the longest tangents, as, for instance, on that across the steel bridge, the flume shell is laid with broken joints—only three or four butt joints (of the 19 staves, including bottom and side planks, each 16 ft. long) being made against any one rib; and the balance of these joints being distributed, according to a system, between the ribs. The butt joints of this construction are closed on metal tongues let into saw cuts in the ends of the staves and planks, as is done in wooden stave pipes.

The sills and yokes were milled, put together and dipped in hot coal tar, in the company's yards, and the steel binding rods were there bent to form, also. These and all other parts of the construction were hauled to and distributed along the work in due proportion and quantity, in accordance with schedules prepared for each point of delivery and route of subdelivery. The concrete footings had been put in some weeks in advance, to admit of hardening, when flume construction commenced.

After subdelivery along the bench, of all the materials except the staves and side boards, a gang of four men in advance put the yokes on

the ribs, and the ribs on the bolsters, and otherwise prepared the frames and assembled the small materials in place for each bent. One of these men was a carpenter; the others, laborers.

Two carpenters and two laborers, under a foreman carpenter, followed, setting up, centering, spacing, and orienting the frames to the radii of the curves, and fastening them up in place by nailing the side bars to the sills, temporarily nailing a light furring stringer on each side to the ends of the yokes, and cutting and nailing on the walking plank.

The staves and side boards were then subdelivered along the footway, and assorted and piled in due number, continuously, on top of the yokes. Carpenters, working in pairs, then cut and fitted these into the shell, and lightly set the wedges in the T frames to hold them. Following came a cinching gang of five men under a foreman, who put on the lug pieces and the binding rods and their cross-heads, put in the balance of the wooden wedges, and lightly cinched and wedged the yokes and cross-heads to their bearings. As this was done, the staves were hammered out with a heavy covered mallet to a smooth jointing on the inside and firm bearing against the ribs. This tightening and matting out was repeated at least twice during the month succeeding, as the lumber dried and shrunk; then a tight cinching was given, and, finally, the butt end joints were calked and payed by a special gang, and the water was turned in soon thereafter.

Although this experience has shown that for a flume of this size the screw-bolt head for the ribs is to be preferred to the strap and wedge-key over the yoke, it has also shown the necessity for the wedges between the yokes and cross-heads and the top of the side plank. Without these wedges the screw threading would have to be very much longer, and much more labor and time would be consumed in getting a hold and a bearing. These side wedges have to be freely used at first to take the edgeways warp and spring out of the planks and staves. When the lumber has been well seasoned in the work, and before the final cinching is given, a 2 x 3 or 3 x 3-in. hard-pine continuous edging or cap piece (laid flat, if 2 x 3) may be substituted for all but one pair of the wedges to each bearing, thus giving a good top finish to the shell and a broad bearing for the yokes. This was done on a portion of the Santa Ana Canal flumes.

The edgeways spring of the staves, no matter how well and care-

PLATE XV.
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fully seasoned the lumber, frequently causes, in the aggregate, as much as 4 ins. of space on each side, between staves, which has to be closed down when a shell of this kind is first put together. This causes difficulty in getting the cross-heads over the binding rods if there is not extra rod-length to spare. If side wedges are used this extra rod-length need not be provided, and the rods need not be upset and threaded more than 3 ins. in length. For, after the cross-head is on, the side wedges are inserted and quickly take up the space, as the warp and spring is taken out of the staves; and this leaves the screw and nut movement available for the real cinching which follows in at least three repeated operations, as already described. The use of temporary cinching bands or straps in course of construction, to clamp the shell while the permanent rods are put on and caught to the cross-heads, was found to complicate the work and increase the labor cost, and is to be resorted to only in cases of bents holding excessively sprung staves or side boards.

It will be observed that the side bars and the foot plank act as continuous stringers, and experience has shown that they serve to prevent any disturbance of the structure beyond the part hit, when, by a landslide or falling rock, a bent or length or two of the work is carried away. On wider flumes of this kind, it would be well to put side bars or stringers permanently along the top of the structure—fastening them to the yokes, or directly to the ribs—in addition to those which are spiked to the bolsters below. And on deeper works it might be well to introduce some longitudinal bracing on the outside of the shell and between successive bents and frames. The great amount of curvature, however, has served to diminish the necessity for bracing of this kind on the flumes of the Santa Ana Canal.

To prevent the waters washing over the outside edge on curves, the flume is given transverse slopes of 2, 3, 4, 5, or 6 ins., according to the degree of curvature. In doing this the center bearings of the bolsters or sills are kept true to the running grade, the inner bearings on the curves are dropped half the desired transverse slope, and the outer bearings hold up the other half, the tops of all three being properly sloped. And then, in passing from curve to tangent and the reverse, the change is made gradual, by the eye, in setting the frames. The result gives a noticeably winding or twisted appearance to the finished structure, where the curves are sharp and reverse quickly.

This adjustment complicated the work much at every step, especially the setting of frames and cutting in the staves. When, however, it is remembered that the mean velocity of water, when flowing full in the completed work, will be about 9.6 ft. per second, and that for economy and compactness the cross-heads are to be only 8 ins. above the water's surface, the necessity for the arrangement will be apparent without the labor of calculation.

In this whole flume structure there is not a nail driven except to fasten the side bars to the sills, and the foot plank to the yokes, and, except temporarily to tack strips of furring in place as stringers, to hold the frames during construction. The parts and bearings where decay starts in ordinary wooden frame flumes are not found in this, and the structural faults of flumes of ordinary building which lead to decay it is thought are eliminated by this design.

The wooden-frame flume commences to rot where the ends of the side posts rest on the sills, and between the planks and the frame, and between the side boards and the bottom boards. Nail holes start decay. The planks of ordinary flumes are nailed to the frames. According to the stage of water, they alternately become dry or nearly so, and again are swelled. Joints open and leak, nails are loosened and leakage occurs around them. Dust lodges in the seams and corners, especially where wet from leakage, and decay follows. And then, when repairs become necessary, the structure has, virtually, to be torn to pieces and built over again, to accomplish a good result.

These special evils, it is hoped, are prevented or in very great measure diminished by the design of the Santa Ana Canal flume. There is no wooden frame to rot at its joints; no plank within a wooden frame to start rot where wood rests on wood; no nail holes to be opened by swell and shrinkage; no leak to start rot. For the Santa Ana Canal experience has proven that this class of flume can be made absolutely water-tight, and a reasonably intelligent and careful attendance (tightening the shell by the screw-nuts and wedges, as the water falls in the autumn, and loosening it, if necessary, as it rises again in spring) will maintain it practically in the same condition. Being kept tight and not accumulating dirt in their cracks and joints, the staves will resist decay for many years. Resting on iron and not on wood outside, their life at these bearings will be very materially increased. The sills, made open, so as to ventilate freely, and for the most part bearing on

concrete below and supporting contact with iron only above, and not being subjected to frequent wetting from a leaky shell, will have a long life. And the same, only in less degree, may be said of the yokes and cross-heads, for they have no nailed joinings with the tops of wooden side posts, or any part specially subjected to decaying influences.

When serious accident comes—and in locations such as the Santa Ana Canal flumes occupy, accidents surely will come from landslides and falling rocks—it is an easy and expeditious matter, as several experiences have shown, to clear away the wreck, with the kind of flume there constructed, and build in a new piece. When decay commences and a plank or stave needs to be replaced, a bent or length of the shell can be quickly taken out, the faulty member rejected, and a new piece put in its place. If it appears that the iron of the binders is rusting, they can be dropped off, half the number at a time, painted all round and put on again without stopping the water's flow. When it appears that the iron of the ribs is rusting next the shell, or the wood of the shell is decaying in that bearing, during the season when the flume is not in use the whole shell can be "knocked down," the ribs cleaned and painted, the lumber swept clean and tarred on the ends, and replaced, for a sum that will be small compared to the value of the new life given the structure.

As stated, the Santa Ana Canal flumes are finished to half the intended capacity only, and the expectation is, ultimately, to raise the ribs and put two more planks on each side. This operation is a simple one. The yokes and cross-heads are removed, the straps or bolt heads taken off from the ribs; the ribs spliced at each end with a straight piece of the same T-iron fastened on with a pair of fish plates bolted by the holes already in the iron; the bolt heads or straps placed on the top ends of the ribs thus lengthened; the same yokes replaced and the ribs enlarged, are ready. The binding rods are spliced by any one of several ways which will be apparent to the engineer; additional side boards put on and lugged out to the ribs; the cross-heads and yokes cinched down; the new butt joints calked and payed, and the work is accomplished.

Such enlargement can be carried on even while the flume is in use, by working one bent at a time in any one place, and it will be seen that it is attended with no sacrifice of the structure as built, and can

be accomplished with a proportionately small amount of labor and material.

Thus it is believed that, although this flume cost somewhat more than would an ordinary one of equal capacity, considering the points above brought out, it will have cost no more when enlargement is completed, and will be still a good flume when two ordinary flumes in succession would have rotted away.

Cost of Flumes.—Division I.—There are nine reaches of this flume, aggregating 11 394 ft. in length, and not including 34 ft. of laps into masonry and concrete structures, built in the cañon division of the work at a total cost of $51 392 50. This included all cost of grading the flume benches, through cuts, and cuttings in the tunnel approaches whereon the flume rests, all substructures and foundations, all delivery and subdelivery of materials—in fact, every cost chargeable, except roads and skidways for delivery and subdelivery purposes, tools and implements, superior superintendence, engineering and accounting,

With respect to parts of construction, this expenditure is subdivided as follows:

Grading—Tunnel approaches—Contract work....	$3 388 14	
Bench and cuts—Force work	15 110 96	
Total	———	$18 499 10
Flume foundation—Excavation	$345 51	
Concrete footings.....	769 64	
Redwood footings.....	192 30	
Total.....	———	1 307 45
Substructures—Excavation of foundation.....	$166 75	
Masonry footings.....	520 40	
Trestles, girders, trusses, etc.....	2 572 73	
Delivery and subdelivery.....	389 00	
Total.....	———	3 648 88
Flume—Materials.....	$21 377 96	
Labor.....	3 949 28	
Delivery and subdelivery.....	2 609 82	
Total.....	———	27 937 06
Total over all.....		$51 392 49

Averaged over its actual length, including tunnel approaches and excluding length of substructures, the bench grading cost $1 78 per linear foot; or, for the flumes' length, which would include length of substructures, the bench grading cost $1 62 per linear foot. Grading in tunnel approaches, under the tunnel's contract, cost $7 53 per linear foot. This last could have been done on force account, even under prevalent adverse labor conditions, for about $5 per linear foot. Force account grading, over all, cost $1 52 per linear foot; of which that in heavy cutting cost about $4, the ordinary location about $1 25, and the cheapest full bench about $1. Under normal conditions of labor and with efficient superintendence these costs would have been reduced, on the average, about 22 per cent. The concrete footings in this division cost about 9 cents per linear foot of flume supported by them, and the excavations to place them cost 4 cents, making a total of 13 cents for this class of foundation. The wooden footings cost 10.4 cents, in place, per linear foot of flume supported by them. Averaged over all, the cost of foundations was 12.6 cents. This, with the average of bench grading, brought the flume support, on bench, to an average cost of $1 74 per foot of line. The flume substructures averaged $3 56 per foot, or 32 cents per linear foot of flume in the division. The average cost of flume support—grade, foundations and substructures—was $2 06 per foot of the flume. The total cost per foot of flume was $4 51, of which $2 22 was for the flume alone, and $2 29 was for transporting its materials, preparing the grade, foundations and substructures for it and putting it in place.

In division II there are six reaches of flume, 1 491 ft. in total length, resting on the wooden trestles and combination trusses elsewhere described (see Fig. 2, Plate XI), and one reach of 1 215 ft., held by the steel bridge and approaches thereto. The cost of this latter piece is given in connection with that of the bridge. The flumes of this division, as now finished for use, are 6 ins. deeper than those in division II—the sides are that much higher—and, consequently, the cost of the iron and lumber in the conduit proper was greater per linear foot of the structure. The labor item in the following account of cost also includes extra work, of no inconsiderable importance, on the six tapering entrance pieces from canal to flume. As these flumes rest on the substructures, except for about one 8-ft. length each, there is no charge for grading or foundations for them.

Subdivided as in the case of flumes in the first division, the cost of these in division II was as follows:

Substructures—Foundation excavation	$217 50	
Masonry footings and piers	720 55	
Trestles, girders and trusses	2 279 73	
Delivery and subdelivery	298 00	
Total		$3 515 78
Flumes—Materials	$2 688 12	
Delivery and subdelivery	165 50	
Labor	771 89	
Total		3 625 51
Total over all		$7 141 29

The substructures in this division, with a total length of 1 440 ft. measured along the stringers, cost $2 44 per linear foot, or $2 35 per linear foot of flume. This latter cost $2 43, making the total cost of these portions of the aqueduct $4 78 per linear foot, and the flume on substructure $4 87 per foot.

Pressure Pipes.

The three pressure pipes of the line cross Warm Springs, Deep and Morton Cañons, respectively. The first named is not a sharp cañon in section; the two latter are exceptionally so. The pipes are of redwood staves bound with round steel rods, and with the end joints closed by metal tongues let into saw kerfs in the stave butts. This latter feature and the special form of coupling used for the binders are the protected elements in what is known as the Allen patent stave pipe. The Excelsior Wooden Pipe Company, which controls this patent for California, were the contractors on the work. And D. C. Henny, M. Am. Soc. C. E., as engineer and manager of this company, planned the structural details of the pipes and directed their building under the specifications. The foundations, supports and bearings for the pipes were put in by the Irrigation Company by day labor, independent of the Pipe Company's contract.

The controlling reason for adopting wooden, and not iron or steel, pipes for these crossings, was that of saving in cost. It must be remembered, not only that the suitable wood for such pipes is cheap on

PLATE XVI.
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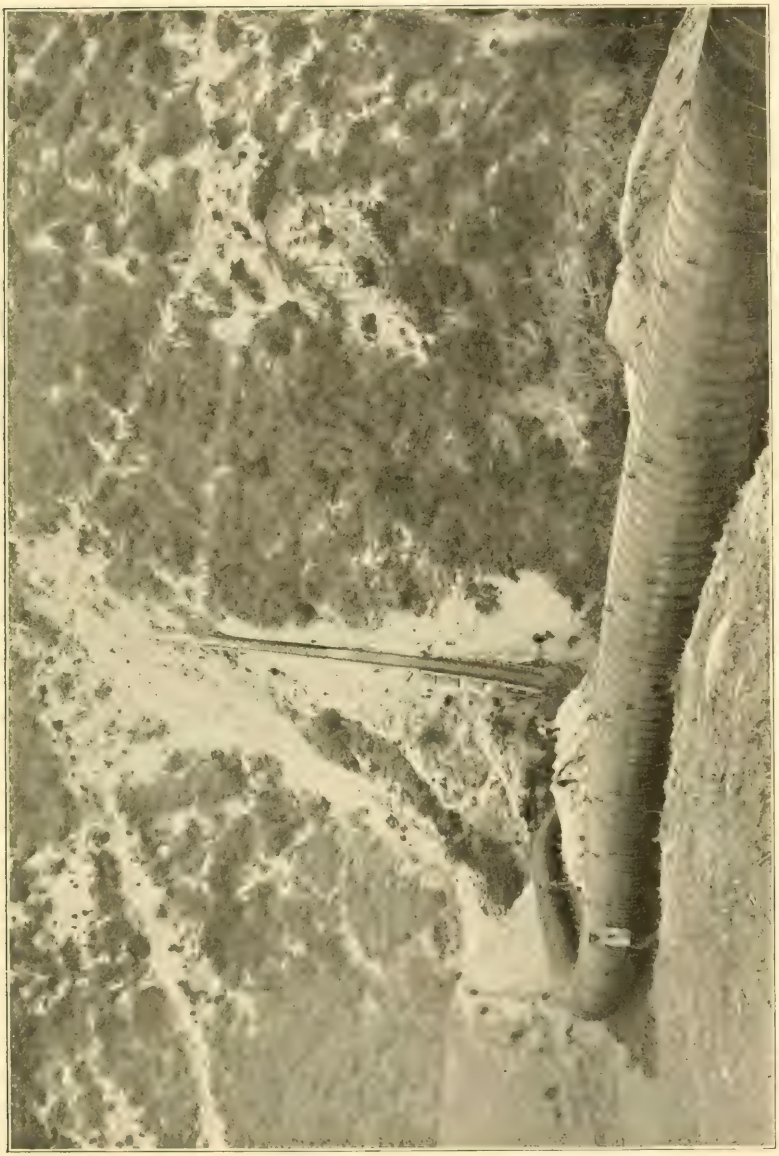


the Pacific Coast as compared to eastern localities, but also that iron and steel, as well as the class of labor necessary to manufacture and put great metal pipes in place, are all, by comparison, high priced on this coast.

And, again, wooden pipes could, with several points of vantage, be laid wholly above ground, thus saving cost of excavation and back filling, which, at the localities dealt with, would have been excessively high; while, on the other hand, it was thought that, owing to the great range of temperature to which they would be subjected, and for other reasons, metal pipes of such very large size would have to be either placed wholly in earth or be expensively anchored and housed.

In this connection, the alternative of doubling the number and diminishing the size of the pipes was preliminarily planned and estimated upon. But when the loss of velocity or necessary increase of hydraulic grade to maintain it, and necessary accumulation of head to force entry, increased width of foundations and of substructures, increased cost and complication of end junctions, and the greater cost of the pipes themselves, were considered, the idea was abandoned. Though it may at first seem a simple proposition to divide the waters of a large flume, having a full-flow mean velocity of 9 to 10 ft. per second between four pipes, and bring them together again into a flume, and maintain good hydraulic conditions uniformly throughout, in fact it is a difficult problem, and one whose reasonably successful solving makes much more expensive work in the junction structures than will ordinarily be justified in irrigation engineering.

As intimated, the reason for putting the wooden pipes above ground rather than in earth is not wholly found in the point of economy, for it is believed that their materials will be less subject to decay when freely exposed to the air; and thus placed, they can be conveniently inspected and kept in repair. Experience in Southern California has shown that sound wood, not subjected to alternate water soaking and drying out, and far enough from the ground surface in the open air for good ventilation and freedom from soil influence, has a very long life. On the other hand, it has here been most abundantly shown that all woods rot rapidly at the ground surface and in the ground, and where subjected to wetting and drying; and, moreover, that there are some soil ingredients which have special wood-decaying influences, and others that attack and rapidly destroy iron and steel.

Owing to irregularity in the ground profiles of all the cañon crossings, it would have been impossible to put the wooden pipes under ground, even for only three-fourths of their length, without either introducing metal elbows or incurring an expense for cutting through high points, absolutely forbidding in amount. Such large pipes cannot be built on curves of materially less radius than 250 ft. with staves 2 ins. thick, or less than 300 ft. with staves 2.6 ins. thick. For be it understood that curvature in these pipes is attained by forcing a bend, by means of jackscrews, blocks and tackles, or other power appliances, after the staves are put into pipe form and loosely banded and as construction proceeds.

As the above were the stave dimensions thought necessary to be used in the Santa Ana Canal pressure pipes, and as the ground lines undulated on curves of much smaller radii than 250 ft., the pipes could not be built to follow the surface profiles. Metal elbows were deemed objectionable, not only as diminishing the pipe capacities, but as increasing the cost, and as very materially increasing the liability to decay, leakage and failure at the points of joining with the wooden pipe.

By the best adjustment of grades that could have been effected, with the curves allowable, and by limiting the maximum depth of excavation to twice the pipe diameter below the present grade line, which itself even necessitated heavy earth and rockwork, not more than half of the aggregate pipe lengths could have been entirely covered, and about half of the balance would have been only partly covered; and besides this great proportion of the pipes thus subjected to the worst influences for decay, there would have been 14 points of the pipes' entry into and exit from the earth, all again specially presenting rot-producing conditions. And even thus the pipes would have been wholly in air, over the waterways, in the cañon bottoms, and for one-fourth their aggregate length. To go under these cañon waterways would have necessitated four sharp elbows to each pipe, and a heavy expense for excavation, back filling and paving. It is true that the expense of the trestle supports was the alternative; but this was figured at less than the extra cost of burying the pipes.

Moreover, the cañon sides on the two principal crossings were so steep that the back filling would not have consolidated in place; and this, for several reasons apparent enough to the profession, would

have left a bad condition of things. The rocks and soils very perceptibly contained some alkaline or other mineral matters which might attack the wood actively, or the steel of the bands, or both. And, altogether, had the attempt been made to place these pipes under ground, the conditions were such as would conduce to their rapid decay. It will be understood, of course, that there will never be any danger of ice forming in these pipes, and that no reason exists on this score for burying them.

The Bear Valley Irrigation Company has a 48-in. wooden stave pipe, having 3-in. thick staves and under a pressure too light to keep them well saturated, exposed for its full length, of more than a quarter of a mile, in the open air. It is now six years old, and the wood is as sound to-day, inside and outside, as the day it was put in. There is no appearance of deterioration at any point, either of the wood or the steel bands.

Again, the Santa Ana Canal pressure pipes are not coated with coal tar, asphalt or any other supposed preservative substance, because, under the circumstances, it is believed to be the best practice not to coat them. The long life of wood in such pipes is due to its being continuously saturated with water; and, this being the case, the freer scope for action given the water, the better. Not coated, these pipe staves will be saturated through, practically to the outside, to where the water will slowly evaporate, and it is thought that this constant supply of fresh water to the pores will constitute a condition most favorable to the long life of the wood. Under such conditions neither coal tar, asphalt, nor any other coating would do any good; for the wood, being constantly wet, will not be harmed by the air, and, unless the wood is dry when application is made, neither asphalt nor coal tar can be made to go into the pores so as to keep the air out or form an efficient coating.

The lumber of these pipe staves was exceptionally fine in quality, but it was not dry; much of it was quite wet, and after placing in the work it could not, without great detriment, be allowed to dry enough to take a coal-tar or asphalt coating. Moreover, at the season of the year when required under the contract, it probably could not have been furnished dry enough for coating. But suppose the lumber had been seasoned sufficient for coating, such coatings have to be renewed about every four or five years in Southern California, to keep

their influence alive. Now, these pipes can never be allowed to dry sufficiently for a repetition of the coating process, and the writer maintains that a poor or greatly deteriorated coating is worse than none at all on the lumber of a wooden pipe.

The above relates to coating such pipes after construction, and on the outside only. The idea of dipping wooden staves into a bath of asphalt or coal tar before building into a pipe to be under pressure, the writer did not entertain in connection with the work herein described. Experience with woods on the Pacific Coast, redwood especially, pronounces against such process for this purpose.

If it were a seasoned timber stick or plank to go into a dry structure, and especially if near the ground, like the sills of a flume or pipe bearing on a foundation, complete coating with coal tar or asphalt has its beneficial effect in Southern California. Or, if the pipe were to be placed in earth, the exterior coating, especially of asphalt, keeps the soil from it and helps to prolong its life. But for a wooden pipe continuously under water pressure from within, and placed in the air, the natural wood surface is believed by the writer to be the best, and the Santa Ana Canal pipes are evidence of that belief.

The writer is thus specific in stating this case because professional opinion, from high authority, has been privately advanced (though, it is believed, thoughtlessly) to the effect that it would, by insuring a longer life for the pipes, have been better to put them under ground; or, being above ground, they should have been coated. Moreover, this is a subject yet new to the profession and may with profit be discussed.

To one who has not previously considered these points, and especially not in connection with locations similar to those of the Santa Ana Canal pressure pipes, somewhat of a shock may come on seeing them thus exposed to the intense heat and apparent desiccating influence of a Southern California sun and atmosphere.

But for reasons which have now been stated, as well as others which may, at least, be apparent therefrom, the writer is strongly of the opinion that in Southern California wooden stave pipes which are to remain continuously filled with water under pressure sufficient to keep the wood well saturated will have longer life in the air than in the ground, and cannot be benefited by coating; and, that, especially, it would have been a mistake to attempt to put the Warm

Creek, Deep and Morton Cañon pipes of the Santa Ana Canal under ground.

The Pipe Problem.

The pipes herein described are not anchored or held in place, except as they rest in their bolsters and except at their ends where built for water connection, into the masonry of the junction bays. Notwithstanding the steepness of the cañon sides on which two of these pipes rest, and notwithstanding the horizontal and vertical curves in them, the writer does not think it necessary to anchor them, and conceives that at first it might have led to trouble.

Let it be remembered that these pipes are immensely stiff shells of large diameter. As columns to resist springing out of line from longitudinal compression strains, and as tubes to resist buckling inwards from similar strains, their strength is much greater than necessary to meet any stress which will be brought to bear on them, except it be occasioned by a landslide ; and any reasonably cheap anchorage would not avail against such a mishap.

They are open butt conduits, through which not more than a moderate (the normal) velocity can be induced, and to which no shock of "water-hammer" can be imparted. Because wrought-iron pipes, equally strong to perform the primary hydraulic duty required at these crossings, would have to be anchored, if not thoroughly buried, to prevent danger of springing out of line and buckling, can be no reason why the expense of anchorage should be added to the cost of the Santa Ana Canal wooden pressure pipes. Such wrought-iron pipes would not have the qualities to preserve their alignment and form which these wooden pipes unquestionably have.

Carrying out the idea of first finishing the work for half-duty throughout its length, these pressure-pipe crossings are planned for two pipes each. The grading, foundation and trestles, and the connection structures at each end, are made ready for the two pipes in each case, but only one has been built for each crossing. This is 52 ins. in diameter, and is expected to carry 120 cu. ft. per second.

The specifications called for staves 2 ins. thick throughout in the Warm Springs pipe. For all pressure heads under 50 ft. in the other two pipes the thickness was to be 2 ins.; from 50 to 100 ft. of head the staves were to be 2.3 ins. thick, and for all heads over 100 ft. the thickness was to be 2.6 ins. Dressed from 6-in. standard width material,

the staves are about 5¾ ins. wide. A ½-in. bead is run on one edge of each stave, and the sides are rounded to the curves of the pipe's circumference. The lumber was all beautifully clear and sound, but not as well seasoned as was expected and desirable.

The lowest part of the Deep Creek pressure pipe, where it is in vertical curve of 300 ft. radius (to center of pipe), for 32 ft. in length is supported on a pair of trussed girders.

The writer believed that there was no necessity for giving the trusses additional strength to meet any supposed load due to either a downward thrust or bulging tendency, which theoretically would be consequent upon the greater hydrostatic pressure on the lower than on the upper half of the pipe in this upward vertical curve. The result has proved the correctness of this judgment.

Although the pipe has now been carrying its water for a year, the end plates of the truss rods in the span spoken of have never even been brought to their full bearings, notwithstanding there is a smaller factor of safety in their proportioning than in any other member of the truss. Not only do these plates not show any sign of crushing into the wood, as unquestionably would appear if they were so loaded, but they have never been brought to a snug bearing over all their surface on it. There is no evidence or indication, in any part or bearing, of the trussed girders being fully loaded, even, much less overloaded, or of the pipe pulling apart either side of them.

As a matter of fact, the appearances are such as to lead to a thought that this pipe is acting in a manner not understood, or, at least, not mathematically demonstrable, to relieve the trussed support of a portion of the load which as its designers the engineers of the Irrigation Company expected it would be subjected to.

In closing this point: As an experiment, with the pipe thoroughly well cinched, the writer would not hesitate to lay it as a tubular girder in 16-ft. spans, between bearings, to support itself and its load of water; and he does not believe that disaster would follow to the Deep Cañon pipe, even were the hog chain rods of the trusses in question loosened up so as to take no weight whatever, leaving only the string girder and the pipe to do the duty.

The Pipes.

Warm Spring Pipe.—The Warm Spring's pressure pipe is 551 ft. long and occupies 540 ft. in length of the line. The maximum head of

pressure from the full-water hydraulic grade line to the inside bottom plane at the lowest point is about 61 ft. The staves are 2 ins. (full) thick throughout. Where set closest together the bands are 5.5 ins. apart from centers, and 12 ins. is the widest spacing. Starting in a downward curve of 250 ft. radius, at a point 20 ft. from the curve's point of tangent with the flume grade plane, it follows on that curvature for 90 ft. in length; then after about 17 ft. of tangent on slope it curves upwards, with the same radius, for about 148 ft.; then almost immediately curves horizontally to the right again with the same radius, while laying on a sharp up grade for about 265 ft. of length, and finally bends down with the same degree of curvature for 41.5 ft., and so enters the lower junction bay. It is on trestle and trussed girder supports for part of its first downward and all of its upward curve, and altogether for 211 ft. of length. The balance of its sills rest on concrete footings.

Cost.—With its substructures, foundations and grading, the Warm Spring's pressure pipe cost $3 513 95, distributed as follows:

Grading		$262 65
Foundations—Excavation	$10 50	
Concrete footings	51 00	
Total		61 50
Substructures—Excavation of foundations	$42 75	
Masonry piers and footings	242 72	
Trestles, girders, trusses, etc	646 38	
Total		931 85
Sundries—V flume	$53 25	
Miscellaneous expense	10 00	
Total		63 25
Pipe—Contract work		2 194 70
Grand total		$3 513 95

This is at the rate of $6 51 per foot for the whole, or $4 06 for the pipe alone, $2 33 for the substructures, pipe foundations and grading averaged over the length of the structure, and 12 cents for sundries. For the length of pipe supported by them, the concrete foundations cost 19 cents per linear foot, or, with the pipe, $4 25. For its length the substructure costs $4 21 per running foot, or $8 27 with the pipe on it complete.

Deep Cañon Pipe.—The Deep Cañon pipe is 964.4 ft. long, and occupies 908.2 ft. in length of the line. For about 405 ft. of length, where, under the greatest pressure, its staves are 2.6 ins. thick, then, each way, for 253 ft. total, they are 2.3 ins., and the 307 ft. remaining have 2-in. staves. The maximum head of pressure is about 160 ft., the closest banding $2\frac{1}{8}$ ins. from center to center of bands, and the widest 12 ins.

Leaving junction bay No. 3, it is laid with a vertical curve, downward, of 250 ft. radius, for 81 ft. of length; then on down slope of about 1 on 3.5, for 185 ft., of which 158 ft. is in horizontal curve, 250 ft. radius, to the right; then a downward curve of 300 ft. radius for 96 ft. in length; then, after 6 ft. of tangent, an upward curve of same radius for 316 ft., and then on an up slope of about 1 on 2, for 280.4 ft., into junction bay No. 4. Where in horizontal curve and on down grade, as above described, it is carried on a trestle 10 to 30 ft. in height. In the short tangent following the second downward curve it lies on a slope of about 3 on 4. For 249 ft. of its bottom curve it is carried on a trestle 30 to 50 ft. in height. There are three substructures aggregating 448.5 ft. in length, horizontally, under this pipe. The balance rests on the ordinary concrete footings.

Cost.—The cost of Deep Cañon pressure pipe, together with the grading, foundations and substructures, is shown by the following statement:

Grading		$1 256 10
Foundations—Excavation of foundations	$36 40	
Concrete footings	177 60	
Total		214 00
Substructures—Excavation of foundations	$175 50	
Masonry piers and footings	819 50	
Trestles, girders, trusses, etc	1 946 05	
Total		2 941 05
Sundries—V flume	$83 50	
Protection bulkhead	72 00	
Miscellaneous expense	30 00	
Total		185 50
Pipe—Contract work		5 631 10
Grand total		$10 227 75

For its 908.2 ft. of length in the line of conduit, this total cost of structure brought the rate to $11 29 per foot, of which $6 20 was for the pipe alone; $4 85 for the grading, foundations and substructures, cost averaged over the length of the pipe, and the balance for sundries. The pipe foundations, exclusive of grading, cost 46 cents per linear foot of pipe resting on them, or, with the pipe, $6 66 per foot. The substructures cost $6 56 per running foot, or $12 76 with the pipe on them. These figures are all based on horizontal measurements.

Morton Cañon Pipe. The Morton Cañon pressure pipe is 756 ft. in length, of which 717 ft. was constructed of the character already stated, under contract, and 39 ft. was built by the Irrigation Company. The entire pipe occupies 679.1 ft. of the running line. For 398 ft. of pipe length, where pressure is greatest, the staves are 2.6 ins. thick; then for 184 ft. total the stave thickness is 2.3 ins., and the balance, 135 ft. of the contract pipe, has 2-in. staves, as also all of that put in on force account. The maximum head of pressure is 158 ft.; the closest banding is $2\frac{1}{8}$ ins. from center to center, and the widest is 12 ins.

Starting in a downward curve of 400 ft. radius, for 70 ft. of length, it then slopes down on tangent for 171 ft. of pipe—falling about 82 ft.—then curves up on a 310-ft. radius for 340 ft. in length, then rises 75 ft. in 136 ft. of length, where the contract pipe ends, and then curves over towards the horizontal with radius 70 ft. for 39 ft. of length into the lower junction bay. Where in upward curve, crossing the bottom of the cañon, it is carried on a trestle for 211 ft. of length and a maximum height of about 25 ft. The balance of the pipe rests on concrete footings.

The 39 ft. of pipe, in curve of 70 ft. radius, could not be built by the ordinary method of springing to the line desired in course of construction, so it was put in by the Irrigation Company's engineers in 8-ft. lengths, with an angle at each end joint. The staves were stagger-lapped 4 ins. at these joints, and joined with the flat-iron tongues, and the succeeding lengths were held together by special L-iron bands let $\frac{1}{4}$ in. into the staves and coupled with bolts. Otherwise the construction and banding were the same as for the balance of the pipes where under a similar head of pressure.

Cost.—The Morton Cañon pressure pipe, with its grade, foundation

and substructure, was somewhat complicated in cost by building the extension curve to join tunnel No. 9 in line in a different and much more expensive manner. The cost was as follows :

Grading		$586 60
Foundations—Excavation	$30 34	
Concrete footings	113 92	
Total		144 26
Substructures—Excavation, foundations	$68 00	
Masonry piers and footings	229 36	
Trestles, girders, trusses, etc	635 77	
Total		933 13
Sundries—V flume	$68 35	
Miscellaneous expense	20 00	
Total		88 35
Pipe—Contract work	$4 440 42	
Extension, force work	630 03	
Total		5 070 45
Grand total		$6 822 79

For the full length in the line, 679 ft., this structure cost at the rate of $10 05 per foot ; of which $7 46 was for the pipe (averaged over all), $2 45 for the grading, foundations and substructures, and 13 cents for sundries. The concrete foundations alone cost 31 cents per foot of pipe over them, or with the pipe, $7 77. The substructure at the rate of $4 40, or $12 06 per foot with the pipe on it. These figures, of course, relate to horizontal measurements.

Paved Canal.

The canal proper portion of the waterway thus far built is through heavy red clayey soil, carrying boulders, cobbles and gravel ; medium soils of the same general character overlying hardpan, and light, alluvial soils overlying boulders in sand and gravel. In all cases the canal excavation extends through the soil and into the underlying strata. It would be necessary, at least, to puddle thoroughly any waterway excavated through these materials, no matter what use the water was intended for or how much, within reason, might be spared for leakage ; for some portions would leak like a sieve without break-

ing, and others would be subject to frequent breaks without previously leaking. In Southern California, where irrigation waters command very high prices, and where waters of irrigation ditches are used for domestic purposes as well, there is to be attained the double object of economy and purity of supply by lining the canals.

Such canal lining is effected by the use of large cobbles and small boulders, laid with or without mortar, as pavements and sloping bank walls, or by the use of cement or asphalt concretes, or plasters variously proportioned and applied. As planned, almost all these varieties of canal lining were contemplated along the line of the Santa Ana Canal, according to adaptability of the materials cut through and convenience of lining materials for use. The constructed part of the canal throughout division II has been lined with large cobbles and small water-worn boulders, the side walls laid in mortar and all grouted and faced with a cement plaster. It is intended that none of the water shall be lost, and that it shall be kept pure for domestic use.

Two general ideas of shaping ditches and laying linings of this class have commonly been followed with slight modifications of each, in Southern California.

The first, as illustrated by the full lines *A B I J* of Fig. 2, Plate VIII, is to form the ditch as a trapezoid in section—the sides sloping somewhere between 3 on 1 and 1 on 1, according to suitability in the material cut through by the excavation and used in raising the banks—and with the bottom level or nearly so across. In such sections the lining is first laid up as a wall, *A B C D E* and *F G H I J*, against each sloping bank, and afterwards, as a separate job, the bottom is paved, *C D G H*, between the wall footings.

The second plan, as illustrated by the full and broken lines *A b c d J* of Fig. 2, is to form the ditch excavation with sides on the desired slope, and join these sides with a rounded bottom whose curvature is so adjusted as to bring the slope lines of the sides of the finished water-way, *E e f g F*, about tangent thereto. In this form the lining is put in by first paving the bottom as an invert, and then immediately, as one job, extending this paving, as a wall, up against each sloping side.

The first plan of lining makes, unless considerable expense is incurred for its avoidance, a weak wall footing, and a broad expanse

of pavement, proportionately, to settle unevenly. From causes which will be apparent on a moment's reflection, cracks occur just on the line of junction of these two parts of the structure, and as the force of the water current and also the grinding action of the sands carried seem to search out these angles for special attention, failures are not infrequently traced to small beginnings here made.

The second plan necessitates laying the pavement first; and then the delivery of materials on and over it, and the unavoidable tramping upon it, causes cracks and uneven settlements; and there are other disadvantages attendant on construction under this plan that seriously affect not only the integrity of the result but the economy of handling the construction force. Moreover, this lining is so far interdependent all around the canal periphery that failure at any one part, near the bottom especially, is more apt to extend to the whole than in the case of work put in under the first general plan. And, finally, the stones used cannot greatly vary in size without making extra work to bring them to even bearings—the supply has to be carefully sorted over in gathering (see comparative sections, Plate IX).

Considering the two plans together, and remembering that the rounded bottom with side slope lines about tangent thereto makes a desirable form of water-way, it is plain that each has its advantages as well as disadvantages.

As will readily be understood upon reference to the cross-section, Fig. 8, Plate IX, also Fig. 1, Plate VIII, the Santa Ana Canal was planned for lining, so as to retain the advantage of building independently walled sides, and at the same time secure the benefits of a rounded bottom and avoidance of a weak corner in the section.

Referring to the diagram for a clearer illustration than words can convey, the excavation was made trapezoidal in section, but the lining was planned to produce a round-bottomed waterway. The walls were built so that about one-fifth in width of the desired bottom on each side was made a part of the wall footing, thus much thickening their base, throwing the lines of connection with the invert out without corners, and making good faces to which to joint the invert paving.

The plan may somewhat increase, over that demanded by either of the others, the amount of material necessary to line a ditch of any given capacity; but the process of laying is much bettered, and the result is believed to be a decided improvement, without necessary in-

crease of cost, over those heretofore attained, at least within the writer's knowledge, in lining large irrigation ditches with this class of material in Southern California.

To the engineer the plans of this class of construction will speak without further comment. But it must be remembered that it is no light responsibility to prepare for carrying 240 second-feet of water at a mean velocity of 5 ft. per second through soils that would melt away like fine sugar under its action if the canal lining should give way, and turn the flood down on to lands worth, where improved, over $1 000 per acre, as they are under some portion of the Santa Ana Canal in division III.

It will be observed from the section that stones of much variation in size can be used in lining by the plan adopted in this canal work, so that less care than ordinary had to be exercised in assorting sizes into the loads, and the larger stones find use where most needed—at the base of the walls. These walls were laid up in irregular layers over a long working face, the endeavor being made to bed every stone in mortar and fill every opening with spalls hammered into mortar. For economy this mortar filling was kept within the front two-thirds of the wall's thickness, the rear third and the space between the stones and the earth slope being filled with earth rammed into place, and slightly wetted to puddle and settle it.

The canal excavation was first made by contract, roughly (untrimmed), to the lines *A B C D* (Fig. 1, Plate VIII). This work was done by the use of ploughs and scrapers; the material was run out endways, for the most part with wheel scrapers, on runways left in or made for the purpose. It was not permitted to cut the banks to make runways, because this would result in uneven backing for the walls.

Just in advance of the wall building the slopes were trimmed down and wall footings excavated to the lines *A b c d* and *e f g D* for the two footings, respectively, leaving a central strip or core of earth, *c d e f*, between the footings, and making a decided foundation trench in which to set the base of each wall. This excavation work was done with picks and shovels, and the material was taken out of the canal with slip scrapers.

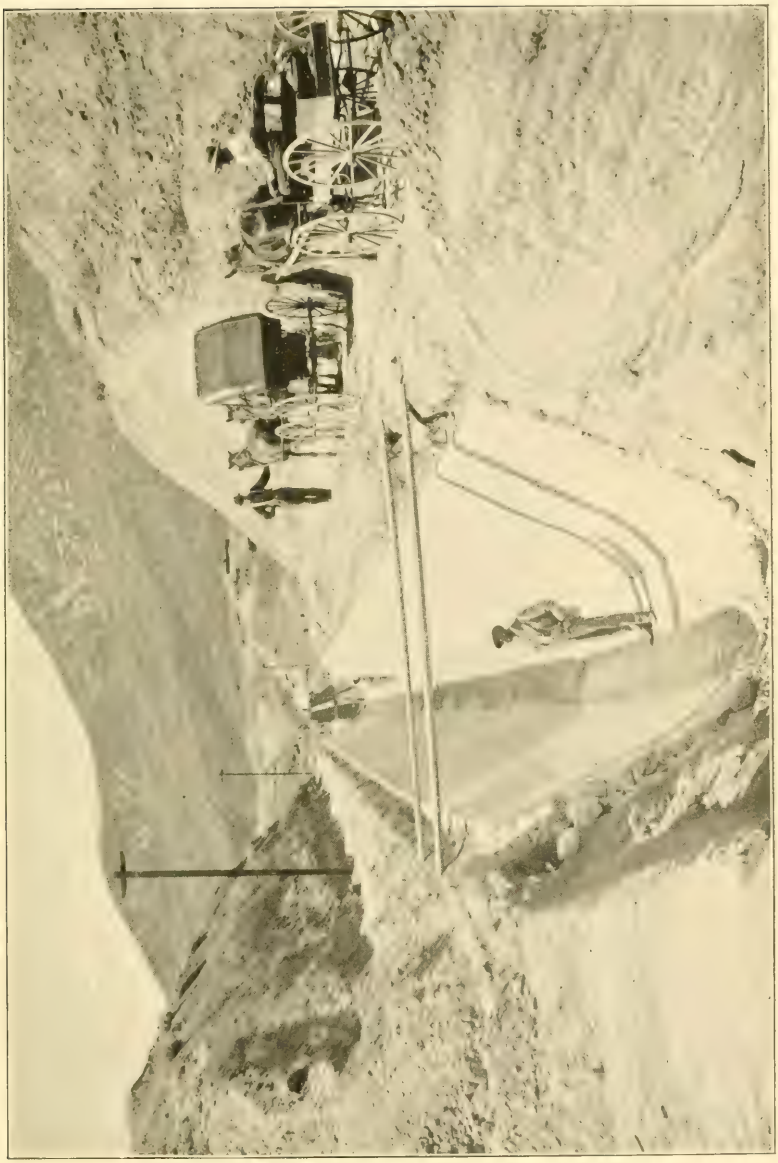
When it is remembered that the stones of this construction were rounded, water-worn boulders, for the most part without bedding faces, that they had to be split when necessary to secure such faces,

and that the work was done by common, unskilled labor, the desirability of having a footing bank and a foundation trench against and in which to bed the wall is readily understood as conducive to rapid and good work.

After the mortar in the walls had thoroughly set and hardened, the bottom was cleared and the necessary additional excavation, to the line *h i j*, was made with pick and shovel, to admit the invert paving between the wall footings. These stones were carefully and closely bedded, dry, in coarse sand, and spalls were hammered into such spaces as would admit them, to wedge the whole together. Coarse sand and fine gravel was then spread and swept with rattan stable brooms over the paving until the interstices became thoroughly well filled. The loose surplus having been swept out, the paving was left with the spaces between stones open, down nearly to the half-depth plane. Mortar was then thrown on and roughly shoveled and trowled in to about the level of and tops of the stones. After this had thoroughly hardened, the cement plaster lining was troweled on, first on the sides and last on the invert. To guide the work wooden centering frames were set at intervals of 16 to 20 ft., and lines were stretched between these by which to lay each course.

During all these processes due care was taken, by the free but judicious use of water, to make and keep the parts and work wet, so as to insure proper bond in setting. In the very dry air and scorching sunshine of summer in Southern California this necessarily constituted no small part of the cost of the work. The plaster, for instance, was kept wet for two weeks after troweling. The water was hauled in iron cylinder tanks on wagons drawn by four horses, sometimes a distance as great as 1¾ miles. Most of the stone was gathered in the wide torrent bed of Mill Creek, and the average haul was about 1 mile. The sand and gravel was hauled from Santa Ana River Cañon, an average haul of over 1½ miles, involving a very heavy pull up and over Morton Ridge, and most of it had to be screened before loading.

The mortar for the walls and invert was made in large boxes at intervals of about a quarter of a mile along the work, and then delivered in wagons, and subdelivered in barrows, where necessary, to the heads of chutes into the work. The cement mortar for the finish plastering was mixed in boxes on wheels carried close along the edge of the work, and run directly therefrom, in metal chutes, down to



where needed. In all this work only common labor was used. It is true that a number of the men had some previous experience and training on work of this special kind, but they were in no sense masons or even skilled masons' helpers. Under favorable circumstances for work and under close and efficient superintendence, as good and cheaper results can be attained in this way, on a large work of this class, than by the use of skilled masons. It is found in Southern California that the higher paid class will, in spite of all that can be done in the way of supervision, be over-particular and slow with this ditch lining, and unnecessarily run up its cost very much.

In viewing this work it is well to remember that there are no soaking rains in this region, and, consequently, no surface or ground-water to lodge behind the sloping walls of the canal linings and spring them. If the canal itself does not leak, the earth through which it is excavated and against which its bank walls are laid will probably remain quite dry for all time. Nearly perpendicular banks of the red clay with boulders, 80 ft. in height, have stood from time immemorial in this section, never having received rainfall enough to wash them, though the soil gives way like sugar when a small stream runs over it for even an hour.

The rounded bottom of the completed canal section is part of a circle, with a $6\frac{1}{2}$-ft. chord and $1\frac{1}{2}$-ft. versed sine, and the sides rise from the ends of the curve, without being exactly tangent thereto, although nearly so, on slopes of 1 on $\frac{1}{2}$, to a plane 6 ft. above the plane of the chord, thus making a total depth of $7\frac{1}{2}$ ft. and total top width of $12\frac{1}{2}$ ft. The full water plane is projected for 1 ft. below the top of the walls, thus giving a water-surface width of $11\frac{1}{2}$ ft. and a water area of 52 sq. ft.

The earthwork was contracted for with a channel bottom width of 7 ft., and side slopes of $\frac{1}{2}$ on 1.* This excavation was afterwards trimmed to receive the lining, as has been described. For all except one length of 275 ft. the walls have been built to a plane 2 ft. below the full finish, as shown at *J* and *K* of Fig. 1, Plate VIII; thus providing, fully, for the half capacity flow, as elsewhere explained. The location was so made that all the side wall, as at present built, rests in cutting. When the additional 2 ft. in height comes to be put on, much of the wall on the down-hill side of the work will rest against em-

* Grant Bros., of Los Angeles, were the contractors.

bankment. It was the intention to form this fill against lagging boards held in place by frames, a year in advance of the new masonry; and, in so doing, to wet and ram it, thus affording a uniformly good backing for all the lining work.

Cost of Lined Canal.—Excluding junction bay No. 7, there are 8 174 ft. of canal to the Alessandro pipe heading in division II. Of this, 483 ft. were in fills where box flumes were temporarily built in, thus leaving 7 691 ft. of channel which was lined. This length of canal is broken into 11 parts by the seven permanent and three temporary flume reaches, and thus there are 20 canal and flume connections made, of which six are with the temporary and 14 with the permanent flumes. The work done and kept account of under the head of "Connections" embraced in the aggregate about 82 ft. of the canal lining. The main part of the lining work, 7 609 ft. in length, was accounted for separately. One piece, 275 ft., of this was lined and finished to the full capacity height of walls as a sample. The balance was finished as heretofore described. The cost of this work was as follows:

Canal—Excavation, contract work	$8 583 52	
Bottoming and trimming, force work	2 667 56	
Total		$11 251 08
Side walls, in mortar	$12 764 38	
Invert, paved dry and sanded	945 22	
Plaster, covering invert and walls	3 696 20	
Total		17 405 80
Total		$28 656 88
Connections with permanent flumes		655 06
Temporary flumes	$599 15	
Connections with temporary flumes	102 25	
Total		701 40
Clearing up—Dressing banks, etc	$127 50	
Cleaning out canal	25 00	
Total		152 50
Grand total		$30 165 84

For the actual length of excavation—7 691 ft.—the earthwork cost at the rate of $1 46 per foot. Under the specifications the fills were built without cost over payment for excavation, so the canal channel

built—8 174 ft.—cost for earthwork $1 37 on the average per linear foot. Some of this work ran as low as 67.5 cents; in the heavy cuttings it exceeded $4, and the cost in normal cuttings was about $1.20 per foot of channel.

The 7 609 ft. of lining work accounted for separately cost at the rate of $2 29 per running foot, of which $1 67 was for the side walls, in mortar; 12.4 cents for the invert, paved and sanded; and 48.6 cents for the plastering of invert and walls.

The total cost per foot excavated, lined and accounted for separately was $3 75; the cost of lining per foot, plus the cost of channelway built, was $3 66. So, had the lining been put into the fills at once, leaving out the temporary flumes and connections therewith, the account for the work would have stood as follows:

Canal lined, 8 174 ft. at $3.664	$29 949 53
Permanent flume connections	505 00
8 174 ft. at $3.727	$30 454 53
Cleaning up and dressing banks	152 50
8 174 ft. at $3.744	$30 607 03

As it is, the summary was as follows:

Canal lined, 7 691 ft. at $3.664	$28 179 82
Permanent flume connections	505 00
Channel in fill, 483 ft. at $1.376	664 61
Temporary flumes	599 15
Temporary flume connections	64 80
8 174 ft. at $3.676	$30 013 38
Clearing up, dressing banks, cleaning, etc	152 50
8 174 ft. at $3.689	$30 165 88

Sand-Boxes.

Sand-Box No. 1.—On Plate VIII are shown plans of sand-box No. 1, located just 700 ft. from the initial point—the headgates' face. Partly hewn into a point of mountain, this may be described as a solid rock and masonry chamber. Within the wall lines it is 60 ft. long by 13 ft. wide, and its floor slopes transversely, so that its depth on the upper or hill side is 7 ft. 3 ins., while on the lower or cañon side it is 10 ft. 6 ins. The interior faces of all the enclosing walls are vertical.

While the floor slopes across to the outer wall, it is broken in

longitudinal profile by three transverse partitions, whose level tops are 6 ft. 6 ins. below the top plane of the main walls and are spaced at 15-ft. intervals from center to center and from the faces of the end walls. These partitions are 6 ins. wide on top, and their sides fall each way, longitudinally of the work, with a 2 on 3 slope. Against the face of each end wall of the structure the bottom rises again with a similar slope, and in the equivalent of one-half of one of the partitions. Thus, the bottom portion of the chamber is divided into four compartments, whose lowest parts, 30 ins. square each, are spaced 15 ft. between centers and lie next the base of the outer wall. To each of these sumps the chamber's bottom planes slope at the rates above given, and in each is located a sand valve which opens downward into a culvert leading to an out-fall on a sharp grade through the outer wall.

The top surfaces of the partitions are in the grade plane of the conduit, so that the sand-collecting part of the structure is in effect composed of four hopper-like compartments, each nearly half of a low, irregular, truncated pyramid inverted, and with the cut-off apex next the outer wall as a sump, in which is its outlet valve.

The flume connections are made through the end walls of this chamber on a line which leaves 1 ft. of clearance from the inner wall to the conduit's side, so that its center line, projected, is 3 ft. 9 ins. from and parallel with that face of the chamber. The inlet connection is a square cut-off of the flume by the chamber's wall, without flare, taper or rounding. But it is intended to change this, as elsewhere explained. The outlet connection is made by carrying the end walls around and the bottom surface up to the flume's opening, so as to produce an approach thereto approximating to the form of the *vena contracta.*

There will be a piling up and disturbance of waters in this chamber, so the walls are planned to a plane a foot above that of the sides of the conduit. It will probably be expedient to raise the flume sides 6 ins. to 1 ft. above the normal, for several bents beyond its intake from the chamber, to where the waters' full velocity becomes again established.

Not counting the sand-hopper space below the plane of grade and of the partition's tops, the water prism in sand-box No. 1 will be, for the half capacity, 39 sq. ft. in area, as against 14.1 sq. ft. for that of the flume. Conceding that it will operate evenly, this would reduce the

PLATE XIX.
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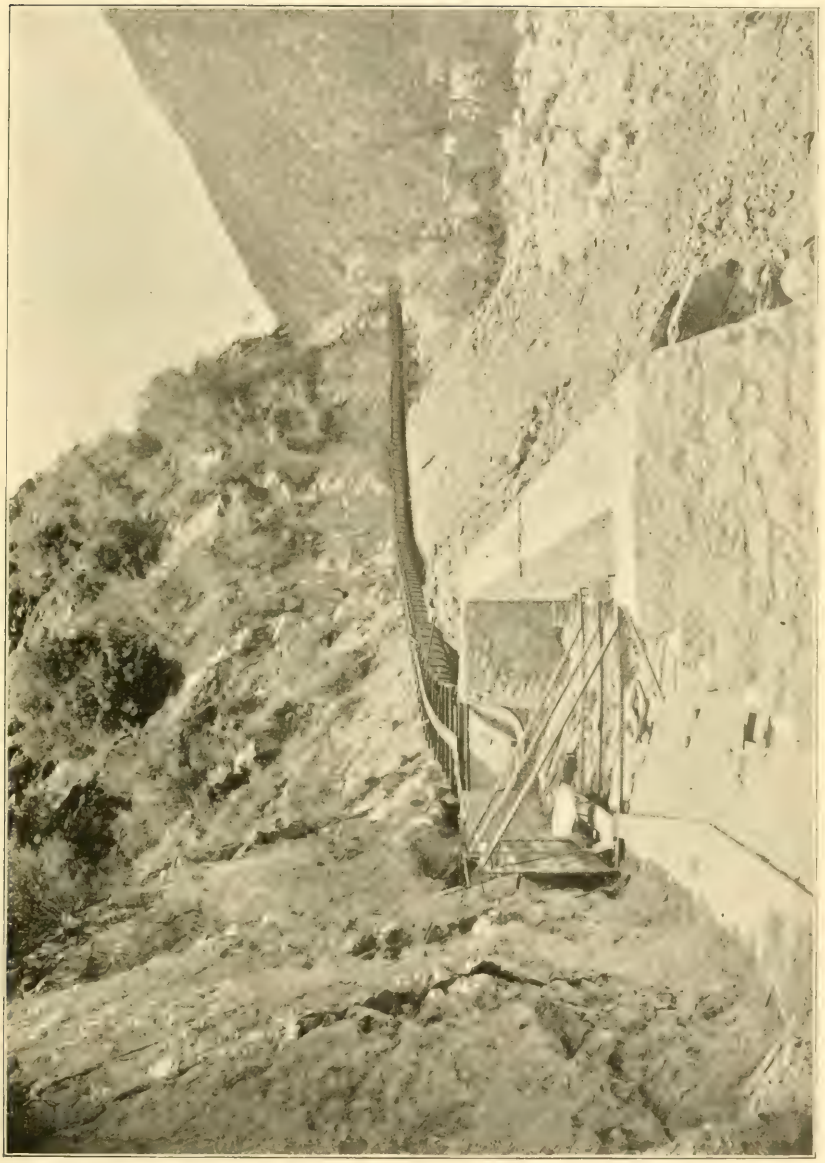
HALL ON SANTA ANA CANAL.



mean velocity from 8.52 to 3.08 ft. per second. For the full capacity the water section above grade in the sand-box will be 65 sq. ft. in area, as against 24.74 sq. ft. in the flume, reducing, in its turn, the current's mean velocity from 9.7 to 3.7 ft. per second. As will readily be understood, this chamber is not large enough to effect the precipitation of finer sands and sediments from waters which will pass through it. Even allowing for the influence of eddies, the mean velocity of water has to be brought down to nearly 1 ft. per second before it drops these lighter particles of its burden.

This sand-box No. 1 is intended to serve all requirements for a couple of seasons, but when the conduit comes to be operated to the full capacity of present finish even (though but half of the ultimate capacity), only heavy sands are expected to be stopped here.

A much larger and deeper settling chamber is projected for a point in the line several hundred yards lower down, and on which dependence is placed to clear the waters of their fine sands and sediments even when the full flow of 240 second-feet is being carried. At this lower point there is ample "dump" below the grade plane, to afford permanent clearance for sands in immense volume. At the location of sand-box No. 1 this dump and the fall away from it are not sufficient to insure the disposal of such a great volume of detritus as the finer sands and sediments of these waters would in a few years produce.

The sand valve used in this structure consists of a truncated, hollow, cast-iron cone with a projecting flange on its base. This valve, with the base down and the truncated end up, is drawn by its stem vertically upwards into the lower end of the short cast-iron cylinder, 18 ins. in diameter, which forms the sluiceway, and in such manner as to make a close joint between the flange base and the end of the cylinder sluice—these faces having been planed with that object in view. Sand settling in the space within the cylinder and around the cone-shaped part of the valve quickly stops all leakage. The valve opening squarely down, away from its bearing, cannot become choked if the outlet below is kept clear. For sand-box No. 1 the outlet culverts are about 36 x 24 ins. in sectional area, and the sluice cylinders and valves themselves are 16 ins. in diameter. The valve stem, of 1¼-in. round iron, passes loosely through the truncating cap of the valve, and is held to it by lock nuts underneath, within the cone. This stem passes up through a three-legged guide, cast in one with the cylinder sluice ; and, thence,

parallel with the face of the chamber wall to a convenient level above the top thereof, where on its end is a hand-power operating wheel. Above the water line a heavy screw nut is held by iron brackets built into the wall, and through this nut the stem passes—itself being provided with the complementary screw of sufficient length to give the valve 20 ins. of movement. This motion is sufficient to drop the valve cone entirely out of the cylinder, so that its base may rest on the culvert's bottom ; and, in this position, the escape area between the top of the cone and the edge of the cylinder sluice is nearly twice the area of the cylinder itself. This device has proved most effective and perfect in operation by several years' use in other sand-boxes of the Bear Valley Irrigation Company's works.*

The upper wall of sand-box No. 1 is 8 to 12 ins. thick, of concrete rammed into place behind mould boards and against the perpendicular face of the hard rock mountain base. The outer side and end walls are of rubble masonry ; inner faces, vertical ; top widths, 2 ft. ; outer face batter, 4 on 1. The outer wall for about a third of its length rests on a base of concrete several feet thick, covering a low recess in shattered bedrock, to make the foundation uniformly good.

The entire structure is upon rock foundation, and with the natural rock backing for the rear wall above described. It occupies what was a sharp rugged point or reef of rock, around whose nearly vertical face the flume might have been carried on bench, or through which, by locating further into the hill, the conduit might have been carried in tunnel. Locating around the point, by flume, would have introduced into the alignment three additional curves—reversing twice—and necessarily of the minimum radius, in order to keep out of cut on the point, excessive for flume location, or avoid trestle supports each side of it. Either of these plannings it was desired for manifest reasons to avoid. Location through the point far enough back for a tunnel would have made approach cutting nearly as much in volume as was taken out for the entire sand-box excavation. The tunnel would have cost nearly as much as the sand-box, and would have been useful only as part of the waterway. A sand-box to take out the heaviest detritus which might pass the heading weirs was wanted as near the head as possible. This rock point presented the very first opportunity for the

* This sand valve is the invention of Mr. J. S. Black, C. E., whose services are hereinafter acknowledged.

outfall necessary from such a sand-box. Hence the determination to carry the work through the point, further back than a flume could have been economically placed, and not as far as a tunnel would necessarily have to be. This location made a first-rate alignment, cheap approaches and good benches each way for the flume, and afforded the opportunity for constructing a sand-box which would not rot out and give trouble. Here, then, we have the reason for constructing what may, without full consideration, seem to be an unnecessarily expensive feature in the work. Of course, a wooden sand-box could have been built several hundred feet further along in the work for less money, but to have kept the aggregate cost at less, the saving would have been made at the expense of a good location past the present sand-box point. No one sand-box would do the duty ultimately required. The one now built occupies the point of advantage for its purpose, and is an absolutely permanent work.

The excavation was carried uniformly down to the plane of the sloping bottom, because it was cheaper to do this than to cut out the hoppers separately, leaving the partitions between. After the enclosing walls were up, the partitions were laid in with dry rubble, well bedded and chinked, and over these and the rock floor a floor of concrete at least 4 ins. thick was rammed into place. The sluiceway cylinders are set in concrete. The sluiceway culverts are of rubble masonry in cement mortar. The entire inside of the sand-box and of the culverts is plastered with cement mortar—over all concrete and masonry faces.

The walls are thus far built to a plane 2 ft. below the full height, this corresponding to the half capacity finish. All the valves are in place, however, and the work is complete in all other respects. A timber staging has been thrown across from blockings on the walls, on which to fasten the screw nuts temporarily and to operate the valves.

Cost.—The work involved 410 cu. yds. of excavation, nearly all rock and much hard rock, which was done with special care in order to save natural walls and an unshattered bottom, at a total cost of $352 10, or 86.3 cents per cubic yard. There are in the structure 160 cu. yds. of uncoursed rubble masonry in cement mortar, including the culvert arches and inverts, which cost $1 242 40, or $7 76 per cubic yard, and 540 cu. ft. of concrete put in at a cost of $178 50, or 33 cents per cubic

foot, and 30 yds. of dry rubble filling cost $31 50, or $1 05 per cubic yard. The plastering 2 115 sq. ft., cost $96 35, or 4.5 cents per square foot. The gates, put in, cost $148 66, or $37 16 each. The staging cost $41 05, and sundries, $27 45, brought the total cost to $2 118.

Junction Bays and Connections.

As planned, between the intake and the delivery to the Alessandro pipe line there are 45 structures, besides those serving merely to unite others. As each structure is different in character, formation or form from both that which precedes and that next below it in the line, there were 44 connections to be made. Four of the 45 structures, namely, two wasteways and two sand-boxes, have temporarily been omitted; and, hence, the connections now made are 40 in number.

To effect six of these, namely, those at each end of the pressure pipe lines, it was necessary to design special works, which cost no inconsiderable amount; and these are herein called junction bays. Two lead from flumes into pressure pipes; one, from pipes to flume; one, from tunnel to pipes; and two, from pipes to tunnels. They have all been constructed to full-capacity finish for the passage of 240 second-feet of water, and are of boulder rubble masonry in cement, with concrete bottoms, except one of the last two—that which joins Morton Cañon pipes to Morton Ridge tunnel. This was designed for concrete and iron, but was built for present use of timber upon a concrete foundation, and is really more in the nature of a penstock than of a junction bay, as the word is herein used. These special structures are all in division I.

In division II, eight of the connections between distinct parts of the waterway required radical treatment, and seven others of another character demanded much work in addition to any equal length of aqueduct either way from them.

But all of these were merely gradual mergings of one form and construction of waterway into another, without the intervention of distinctly different structures. These are brought to the half capacity finish only, though it would have cost but little more, proportionately, to complete them for passage of the full 240 second-feet. The following table gives a comprehensive idea of the extent of this subject and furnishes briefly a key to the manner in which it has been dealt with.

Connections of those classes in the table on page 135 lettered "A" are

at points of but slight change in either form, size or structural character of the aqueduct, and are made by joining the walls of the construction on gradual lines of merging, and plastering thereon along taper slopes set out by a straight edge without any special plan, but so as to avoid even the appearance of any offset or obstruction to the current's flow.

JUNCTIONS AND CONNECTIONS.

Class of Treatment.	Where Placed.		Number Designed.	Number Made.
	Out of.	Into.		
A	Tunnel	Walled canal	1	1
B	"	Flume	6	6
I	"	Pressure pipe	1	1
H	"	Lined canal	1	1
B	Walled Canal	Flume	1	1
C	Flume	Sand-box	3	1
B	"	Wasteway bay	3	3
B	"	Tunnel	2	3
I	"	Pressure pipe	2	2
D	"	Lined canal	6	7
I	Pressure pipe	Flume	1	1
I	" "	Tunnel	2	2
E	Lined canal	Flume	6	7
A	" "	Wasteway bay	1	0
E	Sand-box	Flume	1	1
F	"	Wasteway	1	0
G	"	Lined canal	1	0
A	Wasteway bay	Tunnel	4	3
E	" "	Flume	1	0
			44	40

Those of the classes lettered "B," found in division I, between flumes and masonry structures whose waterways differ but little from them in cross-section, are made by lapping the flume about 2 ft. into the structure joined and filling with concrete and mortar the space in the lap around the flume shell. This filling is made against form boards on the outside end, to effect a wall-like facing, and is carried away on long slopes, put in by a straight-edge, without a drawn plan, inside of the concrete lining or masonry, so as gradually to effect the change of form and dimensions between the flume waterway and that of the structure joined. And, finally, these sloping faces of concrete are plastered so as to bring the surfaces neat to the flume's inner edge without shoulder or offset.

The joinings lettered "C," those out of flumes into sand-boxes are planned to spread the flume in 16 ft. of its length to near double

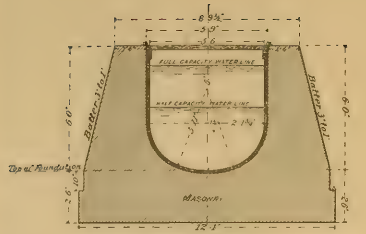
its normal area and to receive it between wing walls from the masonry structure, spreading still more, so as to introduce the water to the chamber at the full width of the latter; the mechanical work of the junction between the wooden flume shell and the masonry walls to be substantially the same as that described last above. But one junction from a flume to a sand-box has been built; and in the haste and enforced economy of finishing the work for immediate use, the flaring part was omitted and the connection made by the flume at normal section in a rectangular end wall of the sand-box. This should and probably will be changed before the works are used to full capacity (see Plate VIII).

Class "D" junctions are from flume to lined canal sections in division II. Here the change of size and form of waterway is radical, but it is from a smaller to a larger section. The flume shell at normal size is joined in the manner above described into a cut-off wall of masonry built squarely across the canal section; and then the transition from the flume to the canal section is made somewhat gradual by a concrete filling laid within the canal section, as shown by a figure on Plate XX, and the interior surfaces are brought smoothly together in plastering, as explained for connections of the two preceding classes. The extra work at these connections is all within about 12 ft. of the running line.

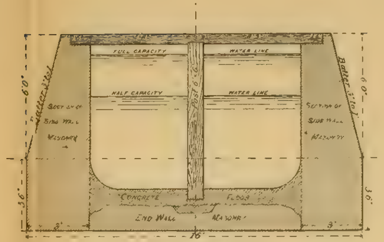
Connections of class "E"—the reverse of those of class "D"—are at points of reduction of the waterway from the larger masonry sections to the smaller wooden section of the flume. The change of form and size of waterway is made, gradually, in 24 ft. of length, of which 16 is of flume and eight is canal lining work; and the mechanical junction between the two is made in the manner heretofore described within return walls of masonry ending the canal work (see Plate XX). The staves for these connection taper lengths were all worked to and set up in a trial form in the company's yards, the iron bands were there bent and threaded, and the wooden sills and bolsters put together, so that erection in the field was much simplified. Trouble was at first experienced by the binding rods creeping down along the taper as they were drawn tight, but this was soon obviated by the chock pieces shown.

The one connection of class "F" thus far planned—from the wooden sand-box to masonry wasteway—has not been constructed.

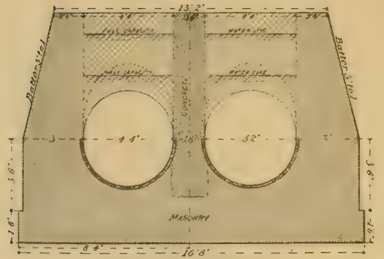
PLAN AND SECTIONS
JUNCTION BAY No1
DIVISION I



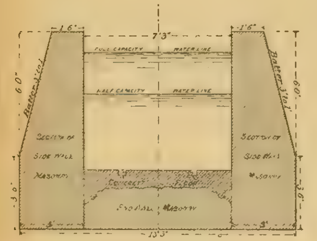
SECTION ON LINE I-J



SECTION ON LINE C-D

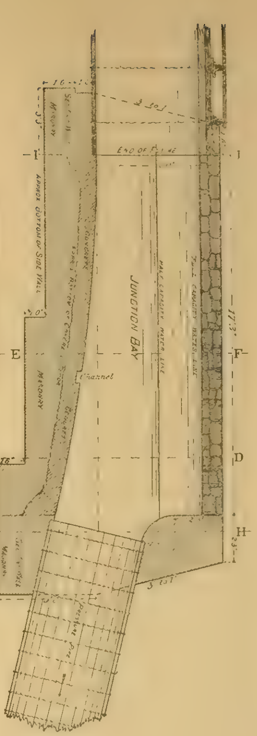


SECTION ON LINE G-H

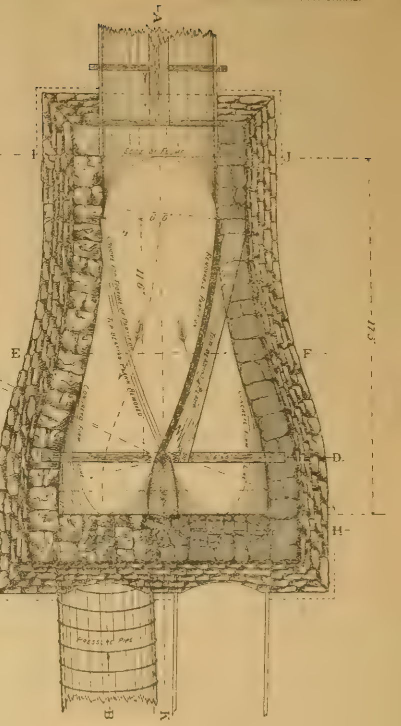


SECTION ON LINE E-F

LONGITUDINAL SECTION ON LINE A B



PLAN



In form its plan is substantially the same as that next preceding, but is reversed in the order of materials used, being from the larger wooden to the smaller masonry section. The one connection of class "G" designed is not yet constructed, being from sand-box to walled canal.

Type "H" has its single exemplification in the connection between the submerged tunnel and the lined canal, and is illustrated by figures on Plate IX, Fig. 10. It is a simple enlargement and deepening of the canal section back to the tunnel portal wall, and is built precisely the same as the canal itself, except that the walls were made heavier at the base as they became higher. This connecting link occupies 40 ft. in the length of the line, and is scheduled as junction bay No. 7.

Plans for a typical masonry junction bay—type "I" are shown by the figures on Plate XX. They represent the structure built at the upper end of the Warm Springs piped crossing, and known as junction bay No. 1. There are five in all, quite similar to this one, completed on the work.

All of these are of boulder rubble masonry in cement mortar. They were built by carrying the walls down to suitable foundations all around, leaving a core of less firm material on the inside at a plane about 8 ins. below the desired bottom grade, and then forming the bottom within the walls with concrete. Some of the foundation excavations had to be carried as much as 6 ft. below the grade planes of the structures themselves, but generally the wall bottoms are 2 to 3 ft. below the floors. All rest upon rock or indurated clay. The flumes and pipes are built into the walls from 1 ft. 6 ins. to 2 ft. 10 ins. in length, and the joinings made in cement mortar. The entire chamber is plastered with cement mortar as described for tunnel finish work.

Plate XX shows plan and longitudinal and cross sections of junction bay No. 1. It is 17 ft. 3 ins. long by 10 ft. 3 ins. greatest width between walls, and its foundation covers a space 24 ft. 3 ins. x 16 ft. 6 ins. Its front and highest wall—that into which the pipes are built—is 11 to 13 ft. high from foundation to crest; interior face, vertical; top width, 2 ft. 3 ins. at 1 ft. above the full-water plane; exterior batter, 3 ins. to the foot, for 6 ft. down to canal grade, where its thickness is 3 ft. 9 ins., and thence vertical to foundation. The back and side walls have top widths of 1 ft. 6 ins., and outside and inside faces the same as the front wall. The lowest, the back wall, which receives

and holds the flumes' shell, is 8 ft. 6 ins. high and 12 ft. 4 ins. across the structure on the foundation line.

The pipes, which are bolstered only 6 ins. apart in the main part of the crossing, are spread to 16 ins. apart where built into the walls of these junction bays, as shown in plan of No. 1, and are cut squarely off and the masonry rounded to them on top, as shown in the section of the end wall appearing in Fig. 2. Between the openings of the two pipes is a concrete partition, projecting from the front wall 3 ft. 6 ins. into the chamber, dividing its end next the pipes into two bays—one for each pipe. This partition is built up from below the floor—out of which it comes—monolithic to the plane of the top of the structure. Its up-stream edge or point is made of a 6 x 6-in. timber built and bolted into it. A tie beam, 6 x 6 ins., caps this timber, extends across the top of the chamber, and is here built at each end into the side wall. This tie beam and the vertical timber post give to the partition whatever strength it may lack to resist lateral thrust when the waters are confined to one side and pipe only, and take the thrust from the removable partition next described.

From the point of the concrete partition, diagonally and curving, as shown in the plan, up stream to each side wall at a point 3 ft. from the flume's entrance, a square-down groove, 4 ins. wide and 3 ins. deep, is made in the concrete of the floor. Two 4 x 14-in. timbers resting on the cross-tie and on the walls and bolted thereto, one above each groove, have their up-stream edges curved to correspond to the curve of the groove below and to set vertically over its outer edge. The groove and these timbers serve as the lower footing and upper bearing, respectively, of vertical 2 x 8-in. needle boards, set in double row lapping seams, like sheet piling. These, extending from the partition's point to the wall and lapping on to each, as shown, form a gate or controlling partition which may be placed in either bearing at will. The form of each, approximating to the curve of the opposite wall, as tending to keep the water passage of even width, will be observed.

In laying the concrete bottom the plane along these grooves was kept free from transverse curve, having the slight longitudinal vertical curve only. Thus, from the upper point of the partition's rest against the walls down to the section *E F*, the chamber bottom is level across and the sides vertical. Above the partition's upper end the corners of

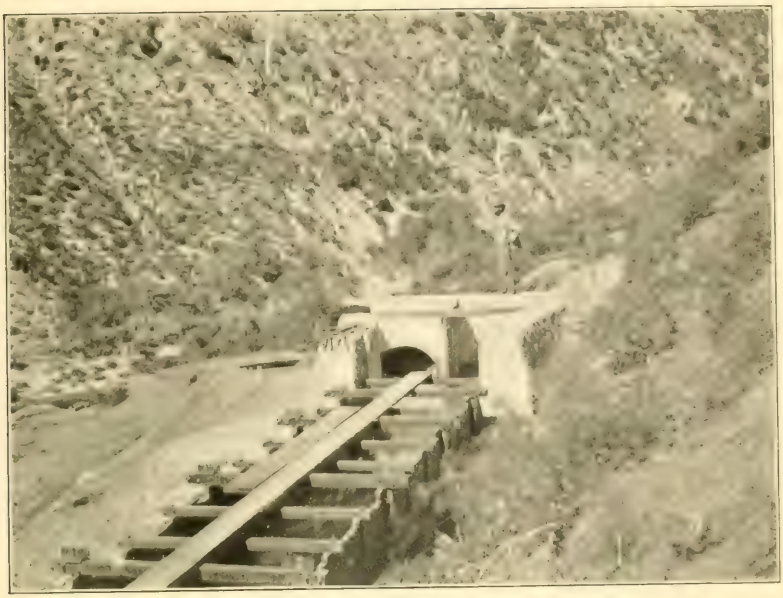


FIG. 1.

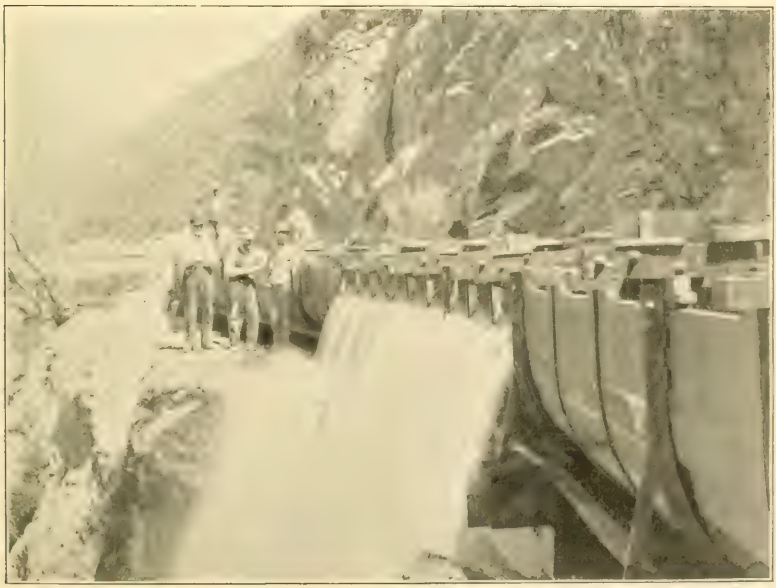


FIG. 2.

the chamber are formed with concrete rounding to the flume form. Below section *E F*, next the outside wall and below the point of the central partition, the chamber's bottom is rounded in the corners by the concrete work and gradually brought to the forms of the pipe bottoms in the two pipe bays.

It is not at all likely that these partitions will be used more than once a year at each piped crossing, to effect clearance of one pipe while the other is in use, unless in the case of accident, and hence it was not thought necessary to design gates admitting of greater ease of operation than do the vertical needle boards.

In this design five points may be worthy of notice—(1) that when in full operation the waters are gradually spread from the flume and are diverted to the two pipe bays by a thin-edged partition, and that the chamber throughout is formed to avoid disturbance of the flow; (2) that the space in the succeeding cross-sections of the chamber has been kept, as near as practicable, commensurate with the duty to be performed; (3) that the structure itself is made, in longitudinal profile, to serve as a downward curve in the waterway, thus enabling the pipe to lead away on a tangent of down grade therefrom; (4) that by this means, also, the pipe intakes are placed in grade, so that the half flow water plane in the flume will submerge and put the requisite entry head over either one separately; (5) that the operation of either pipe by itself is facilitated by the form of closing partition, or gate, which can be placed to guide the waters smoothly and without obstruction into either of the pipe bays.

Junction bay No. 2, at the other end of the Warm Springs pipes, is almost precisely the reverse of No. 1, except that the structure as a whole serves, not only in vertical curve to join the pipes upward gradient at the flume grade, but also in horizontal curve to join the alignments of the two. The introduction of this horizontal curve into the junction bay greatly relieved and simplified the location of pipe and flume, respectively, each way therefrom.

Bay No. 3, at the upper end of the Deep Cañon pipe crossing, is the same as No. 1, except that the pipes lead out of it horizontally and then curve down. Bay No. 5 joins the lower end of tunnel No. 8 with the upper end to the Morton Cañon pressure pipes, and out of it the pipes lead at a descending angle considerably greater than that shown in the plan for No. 1. Otherwise it is about the same. Bay No. 4

joins the lower end of the Deep Cañon pipes to the upper end of tunnel No. 8. Into it the pipes rise on a grade much steeper than where junction is made with No. 2. In other respects these two are substantially the same.

The wooden penstock at the point of joining the Morton Cañon pressure pipe with the submerged tunnel through Morton Ridge is classed with the masonry junction bays only because it is a special connection structure. In design and construction it is radically different from them, for the problem presented at this point was different from any other on the work, to join two wooden stave pressure pipes, 52 ins. diameter each, to one wooden stave tube, 72 ins. diameter, at a point over 16 ft. below the hydraulic grade line; and to preserve them free to access and provide for closing off one pipe while the other should be in use.

The junction work was designed as a monolithic concrete tower of the requisite height—coping of walls 19 ft. above tunnel grade—rectangular in plan outside, and having an oval-shaped well inside. The axial diameters of the well down to the gates' bearing shoulders were to be 6 ft. and 9 ft. 6 ins. lengthways and across the direction of the aqueduct, respectively; and the outside dimensions 8 ft. x 11 ft. 6 ins. at the top, and 10 ft. x 13 ft. 6 ins. at the foundation line. The concrete was to be put together with old steel cables embedded in it, spirally around, to give the walls tensional strength. The plan shows a square cut-off for the pipes inside the well along the face of a concrete shoulder setting 2 ft. 8 ins. into the oval, and iron gates operated from above with power gear, one for each pipe, in runners set in the face of the bearing shoulder, and fitting on to seats over the pipe openings.

In place of this permanent structure there stands a heavy timber penstock of good workmanship, everything being mortised, tenoned and well fitted, and held together by bolts and rods, and resting on a concrete foundation. This chamber is 4 ft. x 9 ft. 6 ins. in plan and 17 ft. 6 ins. deep, inside. The timbers are 6 x 6 ins., 6 x 8 ins. and 8 x 8 ins.; and sills, 8 x 12 ins.; the plank, 2 ins., and the tie rods 1 and $1\frac{1}{4}$ ins. diameter. Provision for wooden gates is made. For the period of its life such a structure will do well enough, but the writer's experience is that wooden-framed structures have very short lives in hydraulic construction in California. Under ordinary circumstances

PLATE XXII.
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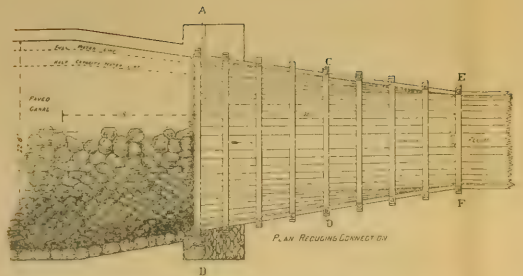
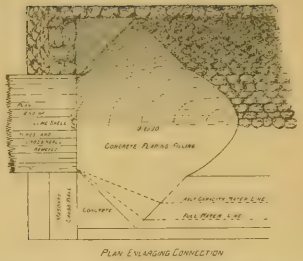
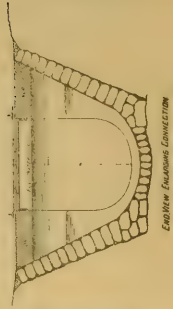
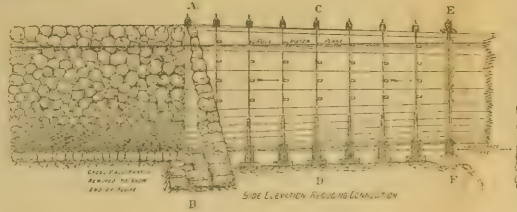
HALL ON SANTA ANA CANAL.

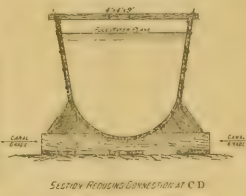
PLAN AND SECTIONS
CANAL AND FLUME CONNECTIONS
DIVISION II











the writer thinks it would be a mistake to build this penstock, but circumstances were such on the Bear Valley Irrigation Company's works at the time it was put in that there was no alternative. The lines of junction of the two pressure pipes with the one tube of the tunnel section are shown by figures on Plate XXII, and this subject, in other phases, is elsewhere referred to. The timbers of the penstock are of Oregon pine and the sills and plank of redwood. All seams were calked with oakum and payed with hot asphalt.

Cost.—No separate account was kept of the extra cost at connections in classes A and C. It was insignificant and not segregable. Those of class B, between tunnels and flumes and other masonry or concrete-lined structures differing but little from the flume in section, cost from $5 to $12 each, according to locality and amount of concrete and mortar required. Those of class D, the entrances of flume into the larger lined canal sections, cost, on the average, about $42 each, of which about $32 to $34 50 was for the masonry cross-wall, and $7 50 to $10 for the concrete filling inside the canal lining. These amounts represent costs, in addition to the canal lining work proper, which latter would thus embrace the plaster finish over the concrete. Connections of class E—the contractions of lined canal into flume sections—cost, on the average, about $71 25 each, of which $27 75 was for the masonry cross-wall, and $43 50 for the 16 ft. of reducing flume in place. This leaves the canal lining, including slope walls, invert and plaster, for the 8 ft. of reducing section in canal construction, to be covered by cost of canal work, as elsewhere shown.

The one connection in class H—from the submerged tunnel to the head of the lined canal—scheduled as junction bay No. 7, and embracing 40 ft. of the running line, cost $432 50, which is segregated about as follows: Excavation, contract work, $50 40; trimming out, force work, $15 40; end wall, concrete foundation, $60 10; masonry, $128 50; lining walls, $72 25; invert paving, $5 25; finish, plaster, $28 65; gate, $14 90; back fill on lower side and shaping banks, $42 05; sundries, unapportioned, $15 20. The paving, side walls and plaster, were averaged with all the canal work of those classes, as elsewhere appears.

Connections of class I, at the ends of the pressure pipes, junction bays Nos 1 to 5, inclusive, those of masonry, cost as follows: Excavation of foundations, $70 35; walls, masonry, $2 616 79; floors and shaping interiors, concrete, $204 61; finish, plaster, $130 77; woodwork,

$112 02; total, $3 134 54; average, per structure, $626 91. In addition to this, there are charges of $883 31, for contract grading of approaches to tunnel No. 8, in which junction bays Nos. 4 and 5 are built, and also $99 60, force account grading, in the aggregate, at the five sites. These grading costs, however, though properly charges against the sites, are not set against the structures as such. The cheapest of these bays cost $556, the average of the two at the Warm Springs Cañon crossing; and the most expensive, that at the north end of the Deep Cañon pipe, cost $714; both inclusive of foundation excavations, but not of the grading above the plane of the flume grade at the sites. Why the latter cost so much the more, though it had less work in it, is elsewhere made plain.

Junction bay No. 6, the wooden penstock, with some outside work, cost $403 20; of which $54 60 was for the concrete foundation, inclusive of excavation therefor, $336 20 was for the penstock proper, and pipe and tunnel connection therewith, and the extra work in the 16 ft. of tunnel lining made to flare to an oval at the penstock joining, and $12 40 was for drainage at north end of the tunnel and under the penstock, to provide for possible leakage. At this site also, there is a charge of $128 for grading the tunnel approach wherein the bay is built.

Wasteways.

Two kinds of wasteways are among the structures on the Santa Ana Canal. The first is a sluiceway for turning out the waters of the aqueduct in a body through one or more gate openings. The second is in the nature of a spillway for wasting waters in a long sheet over a lip provided in the side of the aqueduct.

The first plan necessitates the action of an attendant to open a sluice gate before it becomes operative. The second is within limits, self operative, by waste commencing over the spillway lip when waters rise to its level. Works by the first plan are built in division I. The second design was made for division II. In division I the advantageous point of the second design is secured in connection with the first, by wasting waters over the side of the flume fixed as a spillway.

A wasteway, No. 1, is at the intake, as hereinbefore described with those works. Below that there are five planned in division I, and one in division II. Four in division I are at the upper ends of tunnels Nos. 3, 4, 5 and 6, respectively, spaced about 3 200, 6 350, 8 840 and

12 930 ft. from the intake. Two of these are completely built, the other two have only their stop-gates in the aqueduct built, and are operated to effect waste over the flumes' edge. The next one is planned for the lower end of tunnel No. 8, a distance of 17 000 ft. from the head, but is not built, a temporary wasting flume having been placed there for present use.

Of those built, or partially built, the following is a type. In the opening of a masonry portal at the up-stream end of a tunnel a gateway frame is built flush with the face of the waterway—the end of the roof arch being kept back of the end faces of the side walls sufficiently to admit the operation of the gate, in the grooves of the frame, in front of it. This constitutes the stop gate. At present simple flashboards are used for these gates, but the plans call for a channel iron frame gate, moved in the grooves by overhead gearing, within which frame the gate is completed by removable flashboards. This arrangement permits its use as a sluice, by operating the whole frame by means of the gearing, or as a regulator, by keeping the sliding frame in place and removing one or more flashboards from it as may be desired.

Extending the waterway in the same form and size as that in the lined tunnel, a masonry bay is built 18 ft. in length up stream, and into the upper end of this the flume is connected. The outer wall of this bay is made of three masonry piers, each 2 ft. 6 ins. long in the direction of the aqueduct, by 6 ft. wide on the base, and 6 ft. high above grade, and between these piers are two gateways, 5 ft. 6 ins. opening each, with runways built into the masonry. The form of gate above described for the stop-gate is designed for use in the outlets; but here, also, only wooden flashboards are as yet in place. In this position the permanent gates will admit of operation either as under sluices or as weirs. The design provides for setting the outlet gates in iron runners flush with the inner face of the masonry of the piers, thus completing the chamber as a portion of the aqueduct without material obstruction to the water's flow along its side.

In connection with this form of wasteway, by adjusting the flume plank on the outer side to the desired height of water flow for several 16-ft. lengths above, provision is made for a spillway, operative when the stop-gate is sufficiently closed, or when water is running deep enough in the aqueduct. This form of spillway is illustrated in operation on Plate XXI, Fig. 2.

Wasteways of this class have been located at the upper ends of tunnels, because the spacing happened to come about right in the line, and because at these points hard-rock foundations and backings could be had for the masonry, thus insuring its stability with least volume and cost. Moreover, the opportunities for spilling the waste waters over hard rock and conducting them harmlessly back into the river under these points were specially favorable.

Wasteway No. 5, the lower one of the four just referred to, is also to serve as the outlet for waters that are to be dropped from the Santa Ana Canal to the company's Bear Valley and North Fork canals, as elsewhere referred to. The outlet at this wasteway is into a flume which extends about 100 ft. around the face of a rock point to the head bay of the power drop pipe, and provision is made for wasting the whole or any portion of the canal's volume of flow out of this flume sideways down a rock gorge which has a fall of 330 ft. vertical in about 550 ft. horizontal distance to the main cañon bed.

The necessity for these frequent wasteways will be the more apparent when we reflect that an accident at any one of a number of places along the route of this work might be very disastrous to the aqueduct itself, owing to comparatively poor material under its foundations being washed away. This would be the case in the cañons at the pipe crossings especially. Hence, the desire to provide outlets at points easy of access where the patrolmen could quickly divert the full volume of flow, pending its being closed off at the head. All the points of waste are well situated with this object in view, except that at the head of the long tunnel, No. 5; and it is proposed to provide for the operation of this stop-gate from the lower end of the tunnel by means of a cable through it, and to make a long flume edge spillway above it. As elsewhere explained, accidents are to be anticipated consequent upon landslides and boulders rolling from the mountain side above.

Wasteway No. 7 is designed for the lined canal immediately above its junction with the flume crossing of Mill Creek. The object is, by the operation of a combined drop and flashboard gate, placed in runners at the head of the flume, to be able to regulate waste over a spillway, and even effect the full relief of the canal by this means without opening waste gates. The form of canal is not altered in this spillway bay, only that for 100 ft. in length next above the stop-gate the spillway lip is kept at the level of full water flow in the canal so that any

check of the flow by the stop-gate will cause wasting over the full length of the lip. To this end the canal bank on that side is built in masonry, and at the top it simply rolls over, forming the lip, into the side wall of a parallel canal, which is the wasteway channel. The escaping waters here will go diagonally and at a small angle of deflection out of the aqueduct over a lip, just as they come into it at the heading.

Cost.—The combined cost of wasteways Nos. 2, 3 and 5, finished for use as above described, was $561 37. Of this amount $45 60 was for foundation excavation, $390 10 for masonry, $25 37 for concrete, $29 70 for plaster finish, $40 42 for woodwork and gates, and $30 18 for unapportioned expenses. These structures all set in tunnel approaches where the sites were for the most part graded by contract work; but these gradings have been included in the general cost of the flume bench, as elsewhere shown. Besides this, $159 90, force account grading, is charged against the wasteways, principally No. 5, for the bed on which to locate the waste flume; and this flume itself cost $65, making a total of $786 27, of which $484 60 was for No. 5; $104 87 for No. 3, and $196 80 for No. 2.

In addition to the above, there were expended $149 20 for a bench and waste flume leading from the site for wasteway No. 6 to an available point of discharge, together with a connection of the same with junction bay No. 5 for temporary use. This item brings the total expenditure, under the heading of wasteways, to $935 47.

Power Drop.

As illustrating a valuable feature of this enterprise and one of special utility, the proposed power drop may be mentioned. The company already has two canals in operation, which derive waters from the Santa Ana River at its cañon opening several miles below the heading of the new work. The total delivery which will ultimately have to be made to these works will be between 50 and 60 cu. ft. of water per second. The new canal on the mountain side above commands the highest of these lower diversions, and with about 350 ft. of fall to spare within a horizontal distance of a little over 700 ft. Between the new point of diversion and the lower ones, at times of least water flow especially, there is great proportional loss of water in the river channel. Evaporation, as the water tumbles over and

spreads around the hot rocks and gravels of the cañon channel, is intensely active; and for months succeeding storms which have disturbed the channel gravels the loss of water into the boulder bed is still greater.

The double purpose of saving waters thus lost and of acquiring the power head prompted provision for diversion for all the canals together at the new intake and the introduction of the proposed drop. Of course, the drop will be effected through pipes, and there will be available, on the 50 second-foot basis, about 2 000 H. P., gross.

As, owing to great variability of water flow in this work at different times of the year, the available power will run down as low as 200 or 300 H. P., the proposition is to apply only so much as is reasonably constant to such uses as will require a nearly continuous service, and to apply the balance, when at hand, in pumping additional waters for irrigation either out of the gravels of the cañon near the point of generation or by electrical transmission in the valley below. The great value of irrigation waters in this region, and their scarcity compared to growing demand, will justify this utilization, and make it a valuable accessory to the main enterprise; for the power available will be greatest during the months when irrigation waters are most in demand.

Mill Creek Steel Bridge.

The aqueduct across Mill Creek torrent consists of a flume of the character already described, carried through a riveted steel bridge resting upon steel piers with concrete foundation piers. The bridge consists of 19 Pratt spans, 48 ft. each, put up in couples, with a rocking pier at point of junction, alternating with 10 Fink spans, 16 ft. each, in the intermediate braced trestle piers. Total length, 1 072 ft.

Excluding the end abutment walls, there are 28 pier foundations, which are built of concrete in 2-in. plank casings, carried from 6 to 10 ft. down into the boulders of the wash. The end or abutment bearings are of rubble masonry in cement mortar.

Plate XXIII illustrates the principal parts and some details of this bridge. Attention may be drawn to the form of foundation piers as securing connected pier foundations with a small amount of concrete. Observe that the concrete is limited to the compartment of the casing, at each end immediately under the truss bearings, the intermediate compartment being filled with loose cobbles and gravel.

PLATE XXIII.
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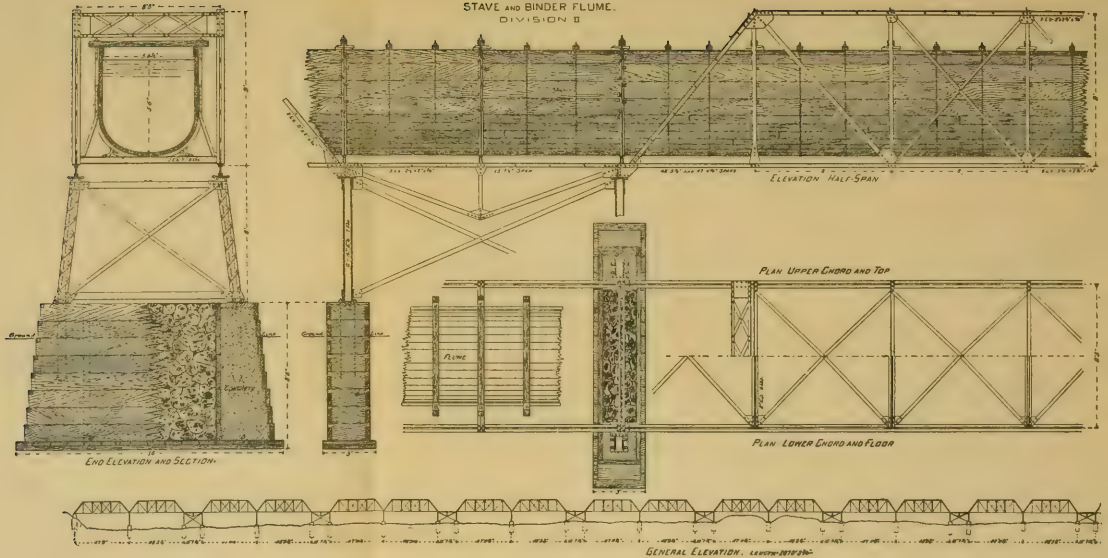
HALL ON SANTA ANA CANAL.

MILL CREEK STEEL BRIDGE
SUPPORTING
STAVE AND BINDER FLUME.
DIVISION II



The foundations of these piers rest on two layers of 3-in. redwood plank, and go down to where it will probably remain unrotted for many years. A better class of foundation pier was certainly to be desired under this structure, but neither time nor means at command would allow of improvement over that which was put in.

Mill Creek is a torrent like Santa Ana River, having a winding channel in this wide wash of boulders, cobbles and gravel. At times of great flood it changes its channel, but its washings at such times are not over 6 ft. in depth through the detritus; and the belief is that the piers put in at least will never be undermined. Should the rolling of boulders batter any one of them badly, this simply involves recasing before another flood comes, as floods are here of very short duration. These foundation piers are 13 ft. 6 ins. x 2 ft. on top, and the subplatforms on which they rest are 16 ft. x 3 ft. for a pier 8 ft. 6 ins. high. The concrete occupies compartments of the casing 2 ft. square on top and larger below, as shown in the section.

As to the construction of the bridge ; the plans illustrate its general features sufficiently, and it would be foreign to the subject proper of this paper to enter into details of a bridge design and building account. The width of bridge between center lines of chords is 8 ft. $5\frac{1}{3}$ ins. The 48-ft. Pratt trusses have six panels, each 8 x 9 ft. Both the floor and top chord system are lattice braced, and portal sway bracing is also introduced.

The floor beams composed of light channel bars in pairs, placed at 8-ft. spaces, and falling at the panel posts of the 48-ft. spans, and at the ends and centers of the 16-ft. spans, also serve as sills for the flume frames. The flange of the T-rib flume frame sets between the two channels ; a cast-iron chock fits up each side of this center bearing, and the L iron bracket braces of the flume bolt on to the iron floor beams just as elsewhere, to the wooden sills of the flume in general, only that for the frames to go on the bridge the bracket braces had to be made longer because the curved center part of the rib was not let down into the sills.

The highest steel pier is 14 ft. on top of a foundation pier 4 ft. above the ground line, and, generally, the structure is 8 to 10 ft. above the boulders of the wash.

This bridge was built under contract by the Massillon Bridge Company, of Massillon, O., according to the plans prepared by Mr. A. Bar-

mann, C. E., under the writer's supervision, but all the erection work was done by day labor.

Its total billed weight, including steel of piers, was 135 740 lbs., as against a plan estimate of 134 254 lbs. The weight used in estimating on cost was 140 000 lbs. Each 48 x 9-ft. truss weighed about 4 840 lbs., and was shipped as a whole on two cars, no serious damage being done the members in transit.

Erection was accomplished by means of derricks and without false work, for there was practically no water in the stream at the time the work was in progress, and a wagon road was constructed the length of the work. The connections were all hot-riveted in erection, and the whole given a coat of red lead in oil after completion, making the second coat from the shop.

Cost.—This steel substructure, with the flume it carries, cost as follows;

For the bridge, 1 072 *ft. in length:*

Foundations—Excavation	$650 10	
Pier casings and platforms	1 024 70	
Bearing pillars, concrete	503 00	
Ballast, cobbles and gravel	49 50	
Back fill and paving around piers	53 75	
Abutment bearings, masonry	56 75	
Total		$2 337 80
Spans and piers—steel, f. o. b. Mentone	$6 380 25	
Unloading and hauling	238 35	
Erecting and riveting	643 20	
Painting, labor and materials	99 95	
Total		7 361 75
Total		$9 699 55

For the flume, 1 215 *ft. in length:*

Grading, in approach		$17 25
Foundations—Excavation	$10 20	
Concrete footings	21 70	
Total		31 90
Flume—materials	$2 175 27	
Labor	389 90	
Delivery and subdelivery	131 25	
Total		2 696 42
Total		$2 745 57
Grand total		$12,445 12

PLATE XXIV.
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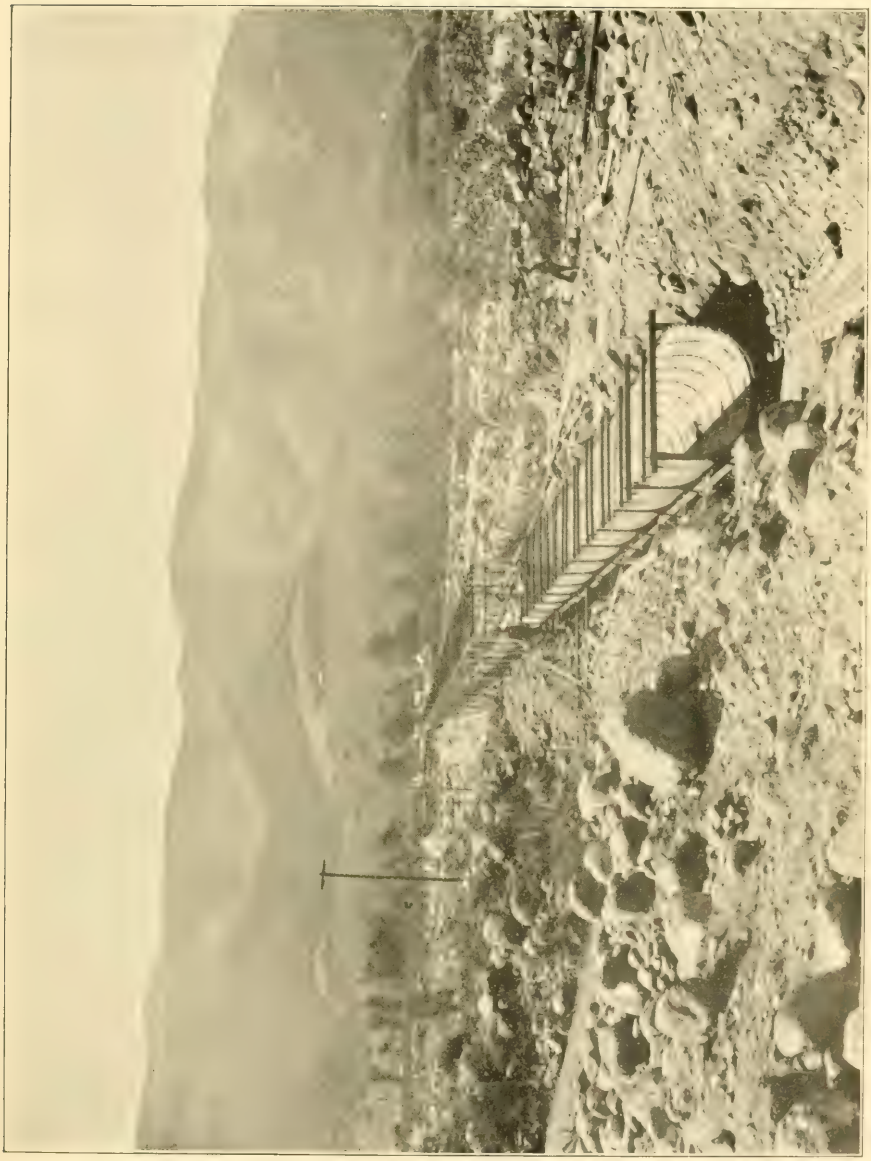
HALL ON SANTA ANA CANAL.



The bridge cost at the rate of $9 05 per foot, of which $2 18 was for the foundations and subpiers, and $5 95 for the steel piers and spans, and 91 cents for delivery, erection and finish of the iron and steel work.

The flume alone cost $2 22 per running foot ; that portion on the ground grade cost $2 57, including grading and foundations ; the bridge and flume, as an aqueduct, cost $11 27 per running foot.

For changes in iron work and experimenting on this piece of flume there were expended, in addition to the above, $143 45 ; thus bringing the total to $12 588 57. But this additional cost is properly a general expense item, chargeable to the entire flume construction, rather than to this one piece alone.

Foundations and Substructures.

All foundation blocks, except those of the flume sills where resting on earth (but a small part of the whole), are made of concrete or of rubble masonry in strong lime and cement mortar. All bearing posts and trestle and timber pier sills rest on such blocks of masonry built on either rock or very firm and hard clay foundations. In some cases these masonry piers had to be carried as much as 8 to 9 ft. below the ground surface. Generally, however, fairly good foundations were had in division I by 2 to 3 ft. of excavation, except at the cañon pipe crossings, where the deepest pits were found necessary ; while at the ravine flume crossings in division II the excavations were generally 4 to 5 ft. in depth.

In every case at the bottom of cañons and ravines the supports of the spans over the waterways were bedded on full masonry subpiers 1 ft. longer and 10 ins. wider than the sills placed upon them. Thus, according to the size and arrangement of posts in the trestle or pier superposed, these subpiers were 2 ft. 2 ins. to 2 ft. 6 ins. wide and 12 to 18 ft. long on top, and with batter slopes, as next described for the separate footing blocks.

Trestle and timber pier bents elsewhere placed were supported by three masonry footing piers each. These little footings were 18 ins. square on top and sloped to 4 ft. square at 5 ft. below their tops, and thence down the faces were vertical. All sills and footing blocks were laid in mortar on their masonry beddings. The tops of all masonry piers and footings were built to at least 18 ins. above ground line, so as to keep the sills free from earth influence.

According to circumstances, the supporting posts used are 4 x 6 ins., 6 x 6 ins. and 8 x 8 ins. The 4 x 6 ins. only for short flume-sill supports, the 8 x 8 ins. in a few of the highest trestles only. The sills and caps of trestles and pier posts are all 6 x 6 ins. or 6 x 8 ins.; the braces all 4 x 6 ins., 3 x 6 ins. or 2 x 6 ins., according to application, generally the larger sizes; the stringers, all 4 x 16 ins., and bolted up in pairs on 1.5 x 3-in. cast-iron separators, are applied in 32-ft. lengths, where admissible, as girders with 16-ft. spans.

The trussed girders are all in 32-ft. spans, and consist in each case of the pair of 4 x 16-in. stringers, trussed with a $1\frac{3}{8}$-in. hog-chain rod, upset at all ends to $1\frac{1}{4}$ ins. before threading, and bearing on plates $\frac{1}{2}$ x $3\frac{1}{2}$ x $9\frac{1}{2}$ ins. Each such rod is divided in the center and provided with a turn-buckle. The trusses are made with two 6 x 6-in. x 4 ft. 9-in. hog posts, provided, of course, with suitable foot and cap castings. All such trusses rest on corbels about 12 x 12 ins. x 2 ft. 6 ins. across the caps.

All truss end supports are made on double postings, bolted up together on cast-iron separators. The general arrangement of trusses and string girders is in alternation, the string girders being within the braced timber pier and the trussed girder between two such piers. All foot and top bearings of posts in trestles were dapped into place and drift-bolted; all sway and string braces thicker than 2 ins. were dapped on or cut around the member closed upon, and all were thoroughly well spiked thereto with wire nails about as long as the wood would admit of. This form of nailing braces for this purpose is preferred to bolting.

All stringers are dapped on and drift-bolted to the corbels, and all corbels are dapped on and drift-bolted to the caps. Nearly all the trestle framing and all the stringer and girder cutting was done in the company's yard, so that only erecting work proper was done in the field.

The flume-supporting substructures are all complete for the full finished work to carry 240 second-feet of water. On the trestle bents and timber piers the flume sills or bolsters are held by three string girders or trussed girders, according to span—whether 16 or 32 ft., as above described—one on each side and one in the center. All flume sills are iron strapped to the outside stringers on which they rest, except in protected places and on curves in the cañon, where they are toe-spiked.

The pipe-supporting substructures are all up, but not quite complete, to carry the second pipe. The weight of the two pipes of water will be greater than that of the full flume, and greater undistributed strains are to be anticipated in the structures under them. The immediate pipe-sill support now consists of two string or trussed girders, according to the span. The one at center of trestle, being intended to serve in part as support to the other pipe also when put on, will be doubled when this is done, and the third one will be placed on the opposite side for the outer support of the additional pipe sills; and, at the same time, additional posting will be introduced into the centers of the bents.

The total lengths of substructures of this class is 3 345.5 ft.

Cost.—In division I there are 36 flume-supporting substructures whose aggregate length for full flume width is 1 024 ft. These took about 46 000 ft., B. M., of lumber, 15 800 lbs. of wrought iron and 4 850 lbs. of cast iron, and cost, erected, $2 857.73; of which $1 859 was for materials, $285 for delivery and subdelivery from the company yards, and $713.73 for labor of framing and erection.

The substructures carrying portions of the Warm Springs, Deep Cañon and Morton Cañon pressure pipes aggregated 880.8 ft. in length, horizontal measurement. There were used in them about 67 000 ft., B. M., of lumber, 7 650 lbs. of wrought iron, and 4 370 lbs. cast iron. It cost $3 228 20 to purchase, deliver and put this material into the work, or $3 78 per running foot. The cost of grading, masonry piers and footings and of the separate substructures is given elsewhere.

In division II, besides the steel bridge there are six substructures, aggregating 1 440 ft. in length. These took about 57 500 ft., B. M., of lumber, 7 640 lbs. of wrought and 3 000 lbs. of cast iron. The cost was $2 537 73, of which $1 541 84 was for materials; $258 for delivery and subdelivery and hauling in the field, and $737 89 for labor of framing and erection.

The Waterway.

There are six classes of conduit thus far designed and built for the Santa Ana Canal, namely, open tunnel, walled canal, lined canal, flume, pressure pipe and piped tunnel. The first three have a smooth cement plaster finish, the last three a close-jointed, planed wood surface.

The waterway through all the open tunnels is designed to one

standard section. The walled canal presents very nearly, but not quite, the same channel, while that of the lined canal is quite different. The pressure pipe and piped tunnel have similarly formed cross-sections, but their sizes differ greatly. The flumes all have the same width and shape of bottom, but those in division II are planned a foot deeper than those in division I. Hence, there are seven standard sections of the waterway provided for in this aqueduct, and (other functions into account as well) seven different mean current velocities will be generated when it is carrying the same volume of water by them all.

Besides minor variations from the expected current rates, which will be caused by curvature in alignment, by the changing from one gradient and form of section to another, and by the influence of conditions immediately preceding and succeeding those of each distinct part of the aqueduct, there will also be variations of flow caused by exceptional treatment of the conduit itself, as, for instance, its division into two at the pressure-pipe crossings.

Within the 29 095 ft. in length now built, there are planned 37 different pieces of aqueduct, besides three sand-box and seven wasteway structures, six special pipe-joining bays, seven special flume-entrance pieces and seven canal-entrance sections. In other words, the water prism is required to change its sectional form and mean rate of movement 36 times after entering the headgate, and 13 special constructions are provided to help it so to do with the least (attainable) loss of head and disturbance of conditions of flow, and 23 other minor adjustments are made to the same end.

Three special constructions are planned as part of the conduit, but, at the same time, for the express purpose of causing the water to slacken its speed and drop its sands and sediments. And seven other arrangements are introduced for occasionally turning the whole or part of it out; but, always with the desire to disturb its normal flow, through or past them, as little as possible when they are not in use.

As elsewhere herein explained, not all of the sand-boxes and wasteways have as yet been built, and some of them have not been commenced. In other respects, though, the general facts shaping the hydraulic problems of the work are as above stated. As the basis of design the study was first made for the full capacity of 240 second-feet, and then for the half quantity, 120 second-feet, of the

proposed temporary finish; and, finally, tests were made by calculation, to see what the conditions would be in the conduit suited to those duties when only 20 second-feet, the supposed minimum working flow, would be running. On the basis of such tests the sizes, forms and gradients of conduits of the different kinds suitable to be adopted were determined. The mean velocities were calculated by Kutter's formula, using Flynn's combined elements and coefficients, and with $n = .010$ for planed lumber and .012 for smooth plaster finish. The calculated results are shown in the following table:

CALCULATED CAPACITIES OF THE SEVERAL PARTS OF THE WATERWAY WHEN FULLY FINISHED.

	Depth of Flow. Feet.	Width of Surface. Feet.	Area of Prism. Square feet.	Sine of Slope.	Mean Velocity per Second. Feet.	Discharge.	
						Second-feet.	Miners' Inches.
Tunnel No. 1	5.3	5.75	29.50	0.00200	8.85	261.0	13 050
Walled canal	5.3	6.00	30.00	0.00175	8.36	250.0	12 500
Flumes Nos. 1 to 9	5.0	5.50	25.08	0.00175	9.71	243.6	12 180
Tunnels Nos. 2, 3, 4, 6 and 7..	5.3	5.75	29.50	0.00175	8.29	246.0	12 300
Pressure pipe No 1	4.33	4.33	14.75	0.00270	8.55	126.0	6 300
Pressure pipes Nos. 2 and 3...	4.33	4.33	14.75	0.00370	10 00	147.5	7 375
Tunnels Nos. 5 and 8	5.3	5.75	29.50	0.00200	8.85	261.0	13 050
Tunnel No. 9	6 0	6.00	28.27	0.00244	10.01	282.7	14 135
Canals Nos. 1 to 7	6.5	11.50	51.90	0.00075	4.94	256.4	12 840
Flumes Nos. 10 to 16	6.0	5.50	30.58	0.00175			

The pipe capacities are given for one pipe only. The depths of water shown for the pipes and the piped tunnel are, of course, the measure of their diameters. The depths for the remaining parts of the conduit are such as would bring the water up to even planes throughout; that is, the differences in depth represent the differences in relative elevation of the bottom planes of the several parts of the aqueduct. Thus, for any one of the open conduits, an apparent excess of capacity over one of another kind merely indicates that, to equalize them, its flow would not have to be as deep as indicated.

Keeping these points in view, to carry the half quantity, 120 second-feet, for which the work is now finished, the depths of flow in the principal parts of the aqueduct would be, theoretically, about as follows: For the flumes in division I, 3 ft.; for the short tunnels, 3.2 ft.; for the long tunnels, 3.1 ft.; for the flumes in division II, 3 ft.; for the lined canal reaches, 4.4 ft.

Again, to carry 20 second-feet, the depths of flow would be about as follows: For the flumes in division I, 1.10 ft.; for the short tunnels, 1.08 ft.; for the long tunnels, 1 ft.; for the flumes in division II, 1.10 ft.; for the canal reaches, 1.7 ft.

These figures, according to our formula and chosen coefficients for roughness, indicate the relative capacities of the several kinds of waterway as built in the work. Taken into consideration with the following remarks, whose application must modify one and all to some extent and at some points, they indicate about the manner in which the parts of the aqueduct are expected to work, without attempting to lay down a water line throughout for any one volume of flow.

Keeping in mind that the desired full capacity is 240 second-feet, the following points may be noted: Tunnel No. 1 was given excess in grade slope and apparent capacity to assist entry at its head. The piece of walled canal was given increase of width and apparent capacity, because, with the labor used, its surfaces were likely to be less true than those of the tunnel and flume, and, indeed, notwithstanding careful supervision, this is the case; there are such irregularities in its walls as will go far towards offsetting the advantage given it by the greater width than the tunnel has; and the rational thought seems to be that the water plane would so adjust itself as to produce about a uniform slope and central velocity from immediately below the intake to the head of the first flume.

Under these conditions the mean velocity would be about 8.7 ft. per second as the water approached the flume. But at that point a head would have to accumulate to produce the additional 1 ft. per second in velocity requisite in the flume section, and, at the same time, raise the center of gravity of the water column about .15 ft. on entering the flume. This piling up of water would have its reflex action on the slope in the conduit above it, probably nearly back to the tunnel. The exact conditions which will exist seem to be indeterminable. This, substantially, would be the case at the point of entry to each reach of the flume from each succeeding tunnel in division I. The adjustments are based on judgment as to such details. The short tunnels, Nos. 2, 3, 4, 6 and 7, are given slightly excessive grade slopes and apparent surplus of capacity merely to further remove the possibility of choking the waterway at these points, which would cause overflow from the flumes above them. That the resultant additional fall due to each

of these breaks in slope, considering the shortness of each tunnel, is insignificant, and that the change in grade slope would not be apparent on the water surface, goes without saying. The break in the bottom plane, due to excess in depth of tunnel over that of flume section, would have a greater influence when there is little water running; and when there is much, both these effects, it was thought, would be effaced, for here again the accumulation of head at the flume's entrance will be the controlling influence on the gradations of surface for some distance each way. The apparent excess of capacity given these short tunnels is to be regarded merely as a slight leaning of the judgment towards what is manifestly the safe side.

A more decided leaning in that way is to be noticed in the still greater grade slope and apparent capacity of the long tunnels. A tendency to choke the water column at the short tunnels might be overcome by an immaterial accumulation of head above them. A proportionate tendency the same way in the long tunnels would be a more serious matter. Our hydraulic formula may be in error, or the coefficients of roughness not well chosen. Hence, the still greater slopes given tunnels Nos. 5 and 8.

Practically the same idea governed in adjusting the hydraulic grade slopes of the pressure pipes; only the problem, for manifest reasons, was considered still more obscure, and hence greater margins were allowed. The short pipe was given slope enough to carry, according to our formula, 6 second-feet more than half the full aqueduct's volume, and the longer pipes were given capacities of about 27 second-feet in excess of the same half flow. The short one might be forced by an immaterially slight accumulation of head, and it opens out into a flume which will surely carry as much as the flume above it. One of the long pressure pipes delivers into the longest tunnel and the other into the piped tunnel, through the penstock, both representing conditions comparatively obscure as to reflex influence on capacity above. Hence, the greater hydraulic grade slopes allowed on the longer pipes than on the shorter. It may be remarked here that these rates of slope are allowed on the basis of the actual lengths of the pipes, and not merely on their lengths as structures, horizontally, in the line. But no special allowance was made for resistance due to curvature. This, under the facts already stated, was thought unnecessary. A sufficient hydraulic gradient was allowed for over tunnel No.

9 to give it apparent capacity equal to the pair of pipes which will ultimately come into it. And, although there is a difference shown by the calculated figures, the result, it was thought, would be that, barring the disturbing influences of the penstock junction, the hydraulic gradient would adjust itself nearly as one plane over these pipes and the piped tunnel in controlling flow through them.

Finally, the alternating canal and flume reaches in division II. As will be noted, the flumes are generally short, and some of the intervening canals are quite short also. Notwithstanding the provision made to facilitate entry from canal to flume sections, and notwithstanding the fact that the flumes are made 1 ft. deeper and with over 20% more area available than sufficient, according to our formula, to carry the requisite amount of water on the gradients allowed, above every flume entrance there would be a head accumulated sufficient to produce the increased velocity necessary to put the water through the smaller flume (than preceding canal) section. What would be the influence of this? Manifestly, such as to change largely the conditions in the canal reach for a considerable distance above. Further, the writer's observation of such matters has indicated that in the cases of the shorter reaches of flume the water plane would not adjust itself to the flume bed at all, but be so influenced by that in the reach of canal each way as to assume some slope (slightly concave and not a true sloping plane) between the level taken by the water surface just within the head of the flume and that in the canal reach below; and this again would be complicated by the counterhead produced in the canal section immediately below the end of the flume in consuming surplus velocity of water delivered from it. In the longer reaches of flume, and especially in that 1 215 ft. in length at the Mill Creek crossing, the water, it would seem, will become adjusted to the flume gradient; but it cannot be so adjusted for nearly the full length of the flume, because the flume section is 1 ft. deeper—its bottom is 1 ft. lower—than sufficient to afford the requisite waterway on the grade set for it, and hence there would be this foot of back water at the lower end of the flume, as modified by the counterhead necessarily created in consuming surplus velocity received from the flume at the beginning of the canal section.

These remarks are not intended as a technical discussion of the problems involved, but merely to point to them and to indicate in a general way the line of thought traversed in designing the aqueduct.

Cost of Work.

The construction herein described is certainly not one in which, even under the most favorable conditions as to labor and material, it might be expected to do work at rates that could appear cheap, compared to results of well-situated examples conveniently disposed for handling. The roughness and inaccessibility of the immediate sites of most of the structures, and the scattered, small and odd-shaped parcels in which, as a general thing, work of any distinct character is found—all conditions tending to increase cost—should be apparent from the foregoing descriptions. The following analysis of costs still further exemplifies these facts:

Rock and Earthwork.—The excavation and movement of earth and rock had a wide range of cost, as the conditions varied. The flume bench grading, of which there was in all about 42 270 cu. yds., cost between 15 cents and $1 41 per cubic yard. About 12 700 cu. yds. of earth cost 15.2, 18.4 and 16.7 cents respectively in the three sections estimated. Much of this was sandy earth, which shoveled freely; most was moved but one shovel's cast, some was cast twice, a small portion wheeled in barrows, a smaller portion scraped. About 27 450 cu. yds. of rock cost 42, 49.5 and 51.5 cents per cubic yard respectively in the three sections. Much of this was soft rock, taken out with pick and cast over the grade, at costs between 30 and 40 cents per cubic yard; a small portion was hard rock, which cost 90 cents to $1 10 per cubic yard, using powder, gads and crows. There was also 2 122 cu. yds. of tunnel approach work, mostly rock, done by contract at $1 41, transferred into this flume bench account as elsewhere explained. This latter rate was 40% too high for the average of the work done under it. The deterioration of labor efficiency is plainly apparent in the above figures. The work in section III was done after the labor trouble commenced. By comparison of materials, it should have cost at least 10% less per cubic yard than that in section I. It did cost 15 to 20% more. The grading for the pressure pipes cost at the rates of 22 to 26 cents for earth, and 52.9, 49 and 59.9 for the average of each of the three jobs respectively; there being in all 4 660 cu. yds. of material moved, full three-fourths of which was on very steep ground, where it was inconvenient and often difficult to work. Labor on these pipe grades was certainly 25% below the normal in efficiency.

The canal excavation cost, by contract, 24 cents per cubic yard.

The preliminary estimate was 25 cents. Notwithstanding the fact that some heavy cobbles, gravels and even boulders were encountered, and that some blasting had to be done, it was a paying contract. The material was loosened with heavy plows drawn by four and sometimes six heavy mules. The top was taken out sideways, with slip-scrapers, and the bottom lengthwise and up runways, with small wheel-scrapers. The top-soil movement under this contract was worth about 10 to 12 cents per cubic yard; the cobbles and boulders, about 20 to 24 cents; and a very small portion, about 36 cents. Following the rough excavation under this contract, the ditch was bottomed and dressed for lining on force account. As near as can be told, there having been no accurate measurement made of quantity, this work cost between 70 and 80 cents per cubic yard, 30 to 40% more than it would have cost had the labor conditions been normal and superintendence efficient.

The excavation of foundation pits and benches cost, according to location, material, bulk of job and time when done, between 40 cents and $3 per cubic yard. Small excavations in rock, at scattered points, as for flume footings where it was not desired or would not have paid to use powder, ran up the highest. Earth in quantity of course cost the least. The pits for trestle foundations for the pipe substructures, in earth, gravel, cobbles and soft rock cost 81.4, 97.5 and 85 cents per cubic yard for the three crossings. The pits and benches for flume substructure foundations in division I cost on the average $1 26 per cubic yard, the rock generally being hard and the points of work scattered. The pits for foundations of substructures in division II, where there was firm earth, clay and boulders and no rock in place, cost between 90 cents and $1 per cubic yard, and with a labor efficiency at least 25% below the normal. Foundation clearances and excavations for local structures in division I cost, for rock, $1 50 to $1 75 per cubic yard; for soft rock, $1 to $1 25; for earth and clay, 40 to 80 cents, according to circumstances. The labor deterioration on these works was less uniform, but in some later cases reached the extreme of 40 per cent. On the average it was about 20 per cent.

Rubble and Boulder Masonry.—The masonry work is found in 21 structures and 46 substructures. For the latter there were built over 320 footing blocks and pier bases. Of these, about 120 in the cañon division averaged about 1.5 cu. yds. in volume each, and 200 in divi-

PLATE XXV.
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sion II only about .7 cu. yd. Many of these little blocks are at spots on steep mountain sides, difficult of access and inconvenient to work at, and all are strung out over long lines of work, necessitating much movement of force and complication in delivery of materials. Of the local masonry structures, nine had an average of about 3.7 cu. yds. each; five, about 17.4; four, about 60.3, and the three largest, 130 to 160 cu. yds. apiece. These also were scattered and at inconvenient places—more than half—high up on the cañon side in division I.

Still, again, the canal lining, which is not included with the above, is, of course, disposed in thin walls and pavings, so that the labor of delivery and placing materials into it could not be brought to as low a figure as though it were in more concentrated mass.

With respect to quality, the masonry may be ranked in three classes: first, that put in cement mortar to withstand, without backing, water pressure or earth thrust, or to bear heavy weight; second, that also in the form of upright walls, in a strong lime and cement mortar, but backed with earth or reinforced with concrete; and, third, that laid on slopes, as canal lining walls, with less mortar and with still less cement in it. The paving of canal bottoms is not ranked with masonry, but as dry rockwork, though it was afterwards covered in with cement mortar in the process of plastering, and the spaces between stones are, in a measure, thus filled with mortar.

Of first-class masonry there were about 955 cu. yds. put into the work, using 480 bbls. of cement and 48 bbls. of lime, at a total cost of $7 840 59, or an average of $8 21 per cubic yard. Of this, the largest block, sand-box No. 1, cost at the rate of about $7 76 per yard, and this was the cheapest work of the class done, except some small blocks at the lower end of the work, where there was little or no expense for delivery of stone. Materials for the sand-box were all obtained within 300 yds. of the work and without the expense of quarrying, and were delivered in wagons, but over very rough roads. The cement cost, delivered, about $3 60 per barrel. The masonry in the next largest structures, the five junction bays, ranged in cost from $8 41 for those at the Warm Springs' crossing, to $9 75 and $11 41 for bays Nos. 3 and 4, and $10 60 for bay No. 5. For No. 1, the material had to be gathered in the wash and hauled in wagons for 100 to 300 yds.; then taken up a tram or skidway in small cars, as elsewhere described, and then carted along the bench about 200 yds. For No. 2 delivery was made in wagons

300 to 500 yds., total, with a stiff uphill haul of about 200. Cement for these cost, delivered, about the same as for the sand-box. Rock for No. 3 was gotten off the mountain side above, but at much disadvantage, from large scattered boulders, rolled down to the flume grade, and along it carted to the work. Cement, sand and water had to be hauled from the river wash, a distance of nearly a mile, and elevated about 350 ft. over a steep road, in wagons, and then, in order to get through tunnels and over trestles, brought in small loads on a narrow-gauge truck with one horse for over 1 000 ft. along the bench.

Cement for this work cost about $4 10 per barrel, delivered. Materials for bay No. 4 were hauled in wagons about ½ to 1 mile from where gathered, up a steep cañon road and then carried up the cliff on the tram car about 100 ft. higher. Cement cost about $4 on the spot. Delivery was made to No. 5 in wagons with a haul of over 1 mile, and rising about 400 ft. mostly in two short steep pulls. Cement cost about $3 75. There were 273.2 cu. yds. of masonry put into these junction bay walls, at a total cost of $2 616 76; average, $9 51 per cubic yard. This class of masonry in tunnel, portal and wasteway structures, where the masses were smaller and the forms of laying more expensive, cost, where delivery was a small item at the headworks, $8 18 per cubic yard; on the lower benches, $10 32; on the higher and more inaccessible sites, $11 20 and $11 32, and at the most inaccessible point, tunnel No. 6 and wasteway No. 5, to which all materials had to be brought, as in the case of water, sand and cement for bay No. 3, the cost rose to $12 64 per cubic yard. In the little blocks for flume substructure footings on this mountain side in division I the masonry cost $11 18, $12 and $12 10 in the three sections accounted for separately; with the cement, subdelivered, at $3 75 to $4, and subdelivery of other materials varying as above described.

In the Warm Spring pipe substructure footings and pier bases, where rock was gathered in the wash close around, and there was no expense for delivery of water, this class of masonry cost $5 92 per cubic yard, with cement at $3 65, delivered. This same class of work at the Deep Cañon crossing, rock gathered in river wash, and all materials, except water, hauled about a mile up a steep cañon road, cost $10 05 per cubic yard, with cement costing $3 60 on the spot. And at Morton Cañon pipe crossing, with cement at the same figure and water equally convenient, but less haul for other materials, the cost was $9 40 per cubic

yard. In division II, where there was no expense for subdelivery, all materials being dumped conveniently from wagons, and with cement at a uniform cost of about $3 50 per barrel on the spot, this class of masonry cost between about $5 90, where there was no haul for rock and but little for sand and water, and $10 60 where all materials had to be gathered at disadvantage and hauled from the river wash over a steep road for about 1¼ miles. In this division the footing blocks of flume substructures cost about $7 per cubic yard, all materials hauled an average of 1¼ miles, but there was somewhat less cement used in these than in similar masses in division I.

Second-class masonry in division I, where delivery was convenient, haul not to exceed 200 yds., no charge for subdelivery, cement at $3 60 and lime at $1 90 on the spot, cost about $4 52 per yard in laying up 158 yds. in walls 1.5 to 2.5 ft. thick and 6.5 ft. high, against earth backings. There were in all 181 cu. yds. of this class of masonry put into the work—using 25 bbls. of cement and 75 bbls. of lime—at a total cost of $838 87, or $4 65 per cubic yard.

The third-class masonry in canal linings of division II was about 4 400 cu. yds. in volume, and in it were used about 553 bbls. of cement at about $3 50, and 811 bbls. of lime at about $1 80 per barrel on the spot. Its total cost was $12 987, an average of $2 95 per cubic yard, but the rate varied between $1 98 per cubic yard—where cement cost $3 45, lime $1 75, and all materials, except sand, were immediately at hand, without haul—and about $4 where the haul for all material was over 1 mile, and the cost of delivering cement and lime was 8 cents greater per barrel.

Bottom paving, dry, chinked and sanded, cost about 60 cents per cubic yard, where the work consisted in simply putting back into paving the cobbles taken out in excavation, and from that up to $2 40 per cubic yard, where the haul was greatest and delivery least convenient. The total volume of this work in the canal was about 1 092 cu. yds.; the total cost, $1 352 85; average, $1 24 per cubic yard, or 2.3 cents per square foot, averaged at 6 ins. thick.

Finally, about 52 cu. yds. of dry rock walls, built as backing and including the temporary headwork's wall, cost $133 83. Some of this was at as low a cost as about 55 cents per cubic yard, where it was a mere matter of piling rocks gathered immediately at hand. Some ran up to several dollars per cubic yard, according to cost of delivery.

Several small jobs of rock fill, aggregating 283 cu. yds. in volume, cost $216 53, with haul all within 200 yds. distance, and materials gathered off the wash.

Concrete.—In the proportions elsewhere given (and as to which there were some unrecorded variations in the practice) concrete entered into 27 distinct structures, besides 24 mere connections, and the flume and pipe-sill fittings. Its cost had a wide range, according to circumstances. That, where all materials were most convenient, with very small charge for hauling them and cement at $3 60 per barrel on the spot—as at the headworks—cost about 29.5 cents per cubic foot; that at the lower end of the works, with materials somewhat less conveniently situated and put into the bridge piers, cost 31 cents ; that in the sand-box, with somewhat more cost for hauling of aggregates, cost 33 cents ; and that in the junction bays, according to cost of hauling and degree of convenience at the work, cost 35.6, 49.3, 41 and 38 cents per cubic foot. Where put into tunnels, behind mould boards which had to be placed and removed at a charge to the result, the concrete cost 32.7 cents at tunnel No. 1, with least cost at tunnel mouth, and 48.5 cents at tunnel No. 7, with maximum cost at tunnel mouth, both tunnels being short and lined for full height of waterway. While for tunnel No. 8—the long tunnel, lined only at bottom and sides 1 ft. high—the cost was at the rate of 44 cents per cubic foot. That put into tunnel No. 9, where the cost of lagging was not a charge against the concrete, with cost at portal a little less than at tunnel No. 8, cost 42.2 cents ; but the work was much impeded and the labor made excessive by the extreme of conditions elsewhere referred to, and the lining work was all done from one end. The flume footing blocks cost at the rates 43.5, 43.4 and 49.1 cents per cubic foot, in the three sections respectively. The pipe footings cost 34, 40 and 39.7 cents per cubic foot. The difference from flume footings is due to the pipe footings being in much larger masses and more conveniently placed for work and delivery of materials. In all there were 18 666 cu. ft. of concrete put into the work, using 748 bbls. cement, at a cost of $7 653 85, or 41 cents per cubic foot.

Plaster Finish.—The plaster-finish work also had a wide range of cost, depending not only on those circumstances which so much affected the cost of masonry and concrete, but on the thickness to which the plaster was spread and the exposure and weather and consequent

measure of necessity for keeping it wet after spreading. The cost ranged from 3.8 cents per square foot—where delivery was most convenient and with cement at $3 50 per barrel—and 6.4 cents under conditions most unfavorable. At the upper end of the work, with cement at $3 60 per barrel and hauling about at the minimum, for the larger pieces of work in the open, the cost ranged between 4 and 4.5 cents per square foot. In tunnel No. 1, same locality, it cost nearly 5 cents. Generally along the high bench, in small quantities, the cost ranged between 5 and 6.4 cents. For the largest surfaces of the junction bays in the same locality, the rates were 4.4 to 6.2 cents. In tunnels on the bench it cost about 6 cents where delivery was highest at tunnel mouth and somewhat less than 5 cents in the long tunnel, No. 8, where cost at tunnel mouth was less. The larger plastering job of the canal, in division II, where more plastering was used in covering the invert, but where delivery was cheapest, cost an average rate of 3.85 cents per square foot covered—invert and walls taken together.

Summary—Masonry, Concrete, Plaster, etc.—Summarizing the work in which lime and cement were used, the following result is obtained :

Classification.	Volumes of work. Cubic yards.	Quantities, Materials.		Ratios—Work to Materials in cubic yards per barrel.		
		Cement. Barrels.	Lime. Barrels.	Of cement.	Of lime.	Of cement and lime.
Masonry, 1st class	955.0	480	48	1.990	19.90	1.81
" 2d "	181.0	25	75	7.240	2.41	1.81
" 3d "	4 400.0	553	811	7.940	5.42	3.22
Brickwork, 1st class	14.0	5	.....	3.000	.....	3.00
Concrete	692.0	748	.....	0.926	.....	0.926
Plaster	183.5	413	20	0.444	9.00	0.424
Totals	.....	2 224	954			

This account is not based on accurate data as to every item. It would have been a useless labor to closely measure the volume of every little block of work which goes to make up these totals, and a hopeless task to trace the distribution of materials accurately and in detail into them. The principal works were dimensioned in the plans

and measured as executed. The smaller works, for which no individual plans were made, were carefully inspected, roughly measured and estimated from such data, and checked by reinspection. Account was kept of materials put into each structure, and instructions were given as to proportioning them into different classes of work. Separate accounts were kept of actual use of materials for each class of work in some of the larger jobs. From such data the account has been made. The fact that the volumes of second and of first-class masonry, per barrel of cement and lime together, are shown to have been the same, is purely accidental, or rather the result of the practice based on the instructions as to proportioning. The proportioning was not always the same in either class—in some works more, in some less, than shown as the averages above. The apparently small amount of lime and cement, the small proportion of mortar, used in the third-class masonry, the canal walls, simply illustrates the fact that these walls are only one tier of stones thick. There was no attempt made to back the lining with mortar; only the bedding joints were filled with it, and where filling was needed between the stones of the wall and the bank slope, earth was rammed in.

In considering these figures it is to be remembered that there was no expense for quarrying. The rock was gathered in the river and creek washes, or on the mountain or hillsides, and piled conveniently for loading. The washes afford an almost limitless supply of suitable clean granite boulders only partially worn and rounded. For some works rock was taken from the flume grade spoil banks, while others of these banks supplied most of the concrete material already well broken. Sometimes large boulders on the mountain side were shot to pieces for the first-class masonry rock, but a very small portion of the whole was obtained in this way, however. The canal lining and paving rock for the first 1 000 to 1 300 ft. of work was gathered from the excavation spoil banks or on the hillsides within 1 000 ft. of where used. That for the last or lower 1 000 ft. was obtained almost entirely in the excavation. For the balance of the lining work the haul on this material was from $\frac{3}{4}$ to $1\frac{3}{4}$ miles.

Sand and water cost about as much, on the spot of use, as rock did per volume-unit used at many points in division I and at some points in division II. Most of the third-class masonry—canal lining walls—and some of the second-class masonry and part of the first class, was put in

with common labor only, men generally at $2 per day, some at higher wages—average about $2.25. Most of the higher class work was put in by masons at $3 to $3 50 per day. The cement used was Gillingham's, which throughout was of uniformly good quality. The lime was a Southern California article, proved by use in other works to have decidedly good hydraulic qualities. Except in the mortar for second and third-class masonry, it was generally used only to make lime water to mix the cement mortar with.

Tunnels.—The actual force work cost of excavation of tunnel No. 9, averaged over its whole length, was about $3 10 per cubic yard. This was through hard, cemented gravel, cobbles and boulders—powder in moderation being required for most of the length and necessarily carefully used. There was some free pick ground in this bore, but not a great deal. This cost was fully 10% more than it would have been under normal labor conditions and efficient superintendence, though the work was finished before the trouble was at its worst. In the other tunnels, at contract prices, the rates varied between $5 25 and $6 10 per cubic yard removed. Actually (according to such accounts as could well be kept on the contract work), it varied between $3 and $6 per cubic yard, the quality of material (all rock, be it remembered), and length of tunnel and expense of ventilation being the chief limiting influences. Under normal labor conditions and with efficient superintendence these contract tunnels could have been driven, on force account, at about 25% less on the average than the contract prices. As it was, although the contractors suffered from the demoralization of labor, they were not nearly so much affected by it as was the company directly; so that, had the rock tunnel work been done on force account, it would probably have cost fully as much as the contract prices, if not more; though, notwithstanding the labor trouble, the contractors made money.

Flumes.—The cost of delivery of lumber for flumes ranged between $2 40 and $3 per M, and averaged somewhat over $2 50. Subdelivery ranged between $1 50 and $5, and averaged about $3 on that actually handled. The higher cost, of course, was for getting the material up the worst cliffs and along the most inaccessible benches. The yard and shop work, consisting of making sills, yokes, reducing sections, etc., and dipping in coal tar, charged only to material thus handled, ranged between $2 50 and $15 per M according to what was done with

it, the average being about $10. The cost of erection charged against lumber amounted to about $5 75 per M averaged over the whole. All labor, inclusive of calking and tarring, charged against preparing and putting lumber into the work, came to somewhat less than $9 per M put in; and this, with the delivery and subdelivery averaged over the whole, made the total rate about $14 per M. The mean cost of all lumber used was about $28 60, and thus we have a total mean cost of $42 60 in the work. Most all of the flume iron cost 5.25 cents at the company's yards. Some cast iron was had at 3.25 cents. The average was about 5.2 cents per pound. The cost of delivery, subdelivery and putting nearly 150 000 lbs. into the work was about $2 000.

It must be remembered that the building of this flume was an experiment. The work was a quarter over before what appeared to be the best method of handling it was settled upon. The erection was nearly half over before there were any really well-trained crews or gangs of men at work on it. Not any one was skilled in it to start in with. There was less effect of the prevalent labor trouble apparent in this flume-building force than in any other, and it was under good superintendence; but even here it is entirely safe to count on a loss of 12% of labor efficiency, due to causes heretofore explained. It is thought that these flume figures will be specially significant to engineers who have had to do with irrigation works and have had experience with ordinary flumes.

Substructures.—The flume wooden substructures cost, for labor of yard work and erection, about $13 per M in division II, $15 50 in division I, and this cost for pipe substructures was about $18 50 per 1 000 ft. B. M. put into them—costs believed to be moderate under the circumstances; but it is thought that under normal conditions of labor this work would have cost 10 to 15% less, even though it was well superintended. This class of lumber cost $19 12½ per M at the company's yards.

The steel bridge cost for erection and riveting – labor, coal, etc.—0.46 cent per pound, or for the steel structure in place, 5.35 cents per pound, a price which will seem to engineers on the Atlantic seaboard enormous for such a structure. The freight from Massillon, O., to the company's yards at Mentone was at the rate of 1.35 cents per pound. And this was at a time of keen competition between the rival trans-

continental roads. The contract price at Massillon, O., was 3.35 cents per pound, f. o. b. Delivery from depot to works and sundries cost 0.19 cent per pound.

Materials.—The appended schedule shows the quantities and range of prices of the several kinds of materials used in the work. It would be tedious to consider them in detail. The writer is satisfied, as a result of careful inquiry on the subject and from his own observation and knowledge, that had the company been prepared to pay promptly, and with this fact substantiated beforehand, it could readily have purchased most of these materials at from 10 to 15% less than it did take them at, and for some it paid as much as 20 to 25% too much. There is no reflection cast by this, except on the bad policy of attempting construction without money absolutely assured to pay for it monthly.

Labor.—The wages paid, as shown by the annexed schedule, were very high for common labor. There was excuse for paying some laborers higher than ordinary, seeing that they were men of some experience in rock and canal-lining work, and on such duty were clearly worth more than the ordinary laborer, or than they themselves were at ordinary labor. But the higher wage rates were sustained throughout for these men on all classes of work. Men who commenced as drillers in rockwork, and skilled men as such, were paid $2 75 per day to the last, long after rockwork was over; and for the most part of the time they were doing for the company work of kinds, for which contractors paid only $1 75 per day. The reason was that the company was in their debt and could not discharge them or cut them down without precipitating a riot. A very significant fact was that they were men who had for years been in the personal employ of the superintendent during each recurring contract season, and who at the time was boarding them and who naturally looked forward to needing their services on his contract work in the future. There were several months when the Bear Valley Irrigation Company was paying (for it afterwards did pay the labor force) at the rate of $2 75 per day to fully 20 men engaged on common labor duty, and doing not more than $1 37½ worth of work each. This is a sample; there are others as bad. It would be useless to cite more of them.

SCHEDULE.—Classification of Expenditures.

Santa Ana Canal, Divisions I and II.

Labor.—Teams and drivers....2-horse, $4 00; 4-horse, $6 00 to $7 00 per day			$12 643 03	
Laborers	$2 00 to $2 75 per day	($2 00)	38 148 80	
Drillers	2 25 to 2 75 "	(2 75)	5 630 56	
Powdermen	2 25 to 2 75 "	(2 75)	470 75	
Masons	3 00 to 3 50 "	(3 00)	2 506 16	
Carpenters	2 75 to 3 00 "	(3 00)	5 060 78	
Blacksmiths	2 50 to 3 25 "	(3 00)	1 258 24	
Foremen and timekeepers	3 00 to 3 50 "	(3 00)	6 970 56	
Total labor				$72 688 88
Materials.—Lumber.—Surf. R. W. flume staves	312 375 ft. @	$32 25 per M.		
Surf. R. W. tunnel staves	35 066 "	" "		
Surf R. W. pipe staves	4 335 "	" "		
Rough red wood	60 483 "	$24 to $30 "		
Surf. Oregon pine	43 275 "	$24 62½ "		
Rough Oregon pine	339 891 "	$19 12½ contract, $21 to $26 small lots.		
Old Oregon pine	7 575			
Total for lumber			$20 964 59	
Iron and Steel.—Bridge steel, 135 750 lbs. @	4.7	cents per pound.		
Cast-iron (comb. spans)	10 214 " 3.05	" "		
Wrought iron (comb. spans)	29 684 " 3.85	" "		
Flume iron (cast and wrought)	214 100 " 5.25	" "		
Iron and steel (sundries)	8 444 " 3.25 to 5.00	" "		
Nails and spikes	4 068 " 2.50 to 3.20	" "		
Total for iron and steel			21 131 95	
Cement and Lime. –				
Cement....2 224 bbls.; contract, $3 10; small lots, $3 50, $3.60				
Lime 954 " " 1 40; " 1 50, 1.70				
Total lime and cement			8 188 55	
Powder, caps and fuse....10 945 lbs. @ 10 to 14 cts. per pound powder			1 366 72	
Oakum 1 675 " 8.5 " " about			139 30	
Paint, asphaltum, etc			212 00	
Brick			54 69	
Blacksmiths' coal 7 250 lbs @ $17 to $20 per ton			77 00	
Zinc (used up)			12 00	
Tiling, tunnel drains			18 00	
Manilla rope (used upon skidways)			200 00	
				52 364 80
Contract Work.—Labor and Materials.—Hauling, at 37½ cts. per ton mile			$3 616 93	
Wooden pipe (separate statements)			12 266 21	
Canal excavation	at 24 cts. per cubic yard		8 633 62	
Tunnels and approaches ($41 538 96 — $1 508 90 rebates, etc.)			40 030 06	
Total for contract work				64 546 82
Total for labor, materials and contracts				$189 600 50

Notes on Above Schedule.—

The usual labor rates are shown in brackets.

Drillers and powdermen worked much time at common labor work.

Much of the masonry of canal work was done by common labor.

Final Summary of Cost.

The following summarization exhibits in most compact form the cost of each class of structure for each division and for the entire work:

Classification.	Division I.	Division II.	Total.
Headworks and temporary supply ditch	$1 151 45	.....	$1 151 45
Walled canal	1 246 23	.....	1 246 23
Tunnels and connections	47 496 03	.....	47 496 03
Pipes and substructures (wood)	20 727 09	.....	20 727 09
Flumes and substructures (wood)	51 392 48	$7 141 29	58 533 77
Flume and steel bridge	.....	12 588 57	12 588 57
Lined canals	.....	30 165 84	30 165 84
Junction bays	4 233 01	432 50	4 665 51
Sand-boxes	2 118 00	.....	2 118 00
Wasteways	935 47	.....	935 47
Zanja superpassage	.....	221 03	221 03
Pipe connection	.....	178 25	178 25
Totals	$129 299 76	$50 727 48	$180,027 24
General expense	$1 775 98	$495 48	$2 271 46
Unapportioned subdelivery	421 08	.....	421 08
Skidways	1 232 36	.....	1 232 36
Road bridges over canal	75 05	168 30	243 35
Roads	4 178 87	1 226 16	5 405 03
Totals	$7 683 34	$1 889 94	$9 573 28
Grand totals	$136 983 10	$52 617 42	$189 600 52

This account does not include $1 000 rebate on tunnel work provided for in the contract, nor $508 90 penalties on tunnel work, reported under terms of the contract. Including these, the total would be brought to $191 109 42. The total on the final estimate of this work was $167 000, not including the last three items above enumerated. Leaving the amount of those items out from the result, the total becomes $182 719 78. Excess over estimate, $15 719 78, or about 8.6 per cent. A careful revision and checking of cost accounts, made on the basis of notes and data heretofore spoken of, afford ground for the assertion that under normal financial conditions and good superintendence, the work could easily have been built for $25 000 less than it did cost, or, say, $158 000, as against the $167 000 of the estimate.

Roads were and are regarded as a permanent property aside from the aqueduct, and hence should so be estimated and scheduled. Construction apparatus and skidways were regarded as part of the company's plant, available for use on other portions of the work and on other works which it has to build. The deterioration of plant should be

charged against this work, but has not been because there has been no opportunity to ascertain it. The general expense item includes amounts for superintendence, clearing brush along line of work, general cleaning up and collecting odds and ends at close of work, etc., and unapportioned yard and mill work. The unapportioned subdelivery is nearly all for subdelivery of cement, lime and bricks, chargeable to tunnels and other masonry structures and footings. The item is so small and would be so much divided that it would not materially affect rates, even if it could be apportioned.

The total cost of works above itemized in division I, $129 299 76, is at the rate of $37 564 per mile. The $50 727 48 for division II represents $24 528 per mile. The mean cost for the entire work, leaving out, as above, general expense and unapportioned items and outside expenditures, was $32 673 per mile, or $272 per mile per second-foot of capacity. But this is not a fair view to take of the construction. It is built for far more than 120 second-feet. At a comparatively small additional expenditure its capacity will be for 240 second-feet. A rough estimate of completion for this amount, based on the experience thus far had, brings the total cost at materially less than $220 000, or $39 900 per mile, or $166 per mile per second-foot. This result would be decidedly cheap for a work of the class and degree of permanence—one which will lose practically no water whatever, except by evaporation—built through an exceptionally rough country as this is.

Of those who participated in this work the following are deserving of special acknowledgment for faithful, energetic and intelligent service : Mr. John H. Quinton, Jr., Principal Assistant Engineer, in general charge of the office and of field engineering ; Mr. A. Barmann, Civil Engineer, who designed the Mill Creek steel bridge ; Mr. James Black, General Mechanical Assistant in office; Messrs. A. L. Sloane and G. W. Sergeant, Engineers in Charge, divisions I and II, respectively ; Mr. W. P. Edwards, C. E., who did most of the finer instrumental work of the surveys ; and Mr. M. L. Slocum, superintendent of the mechanics' (not the general labor) force. Mr. E. M. Boggs, C. E., was in charge of the preliminary surveys for this work, and no small measure of credit is due him for his share in the selection of the general line afterwards located and built upon. The steel bridge work at Massillon was subjected to the inspection of William Barclay Parsons, M. Am. Soc. C. E., and the excellent character of the work and care exercised in loading were no doubt due in no small degree to his service and instruction.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

744.

Vol. XXXIII.—March, 1895.

THE BRIDGE OVER THE TENNESSEE RIVER AT JOHNSONVILLE, TENNESSEE.

By HUNTER MCDONALD, M. Am. Soc. C. E.

READ JANUARY 2D, 1895.

WITH DISCUSSION.

The preparation of a more elaborate paper on this subject was nearly complete when paper No. 713* was presented to the Society. It became necessary, therefore, to revise the original and strike out, as far as possible, those features of the work already described.

The bridge of the Nashville, Chattanooga and St. Louis Railway over the Tennessee River, at Johnsonville, Tenn., was built in 1866 by the Nashville and Northwestern Railroad Company. Brig.-Gen. William P. Innes was Chief Engineer, L. Hutchinson, Resident Engineer, and Charles H. Ball, Assistant Engineer. D. L. McMillen & Co. were the chief contractors, and Flannery & Nash, subcontractors.

* *Transactions*, Vol. XXXI, page 587.

The cost of the substructure was $94 512, and of the superstructure, $73 132. No plans or records (save the minutes of the Board of Directors) are now extant to show the details of the work.

The first bridge was a Howe truss, which was replaced by a combination bridge in 1871, designed for a moving load of 2 240 lbs. per lineal foot.

Mr. Charles H. Ball, who is still living, in a letter dated at Waverly, Tenn., gives the following description of the preparation of the foundations:

"The average depth of the water was between 6 and 7 ft., except at the channel on the west side of the draw, where it was 10 ft. I examined the river-bed, and it was composed of hard blue clay cemented with iron pyrites so hard it was difficult to drive a steel bar into it 6 ins. It was very smooth and nearly level up and down the river the length of the piers.

"The piers were built upon cribs of timber, sweet gum, cypress, oak and hickory, roughly hewn. These cribs were built in alternate layers, with sticks at right angles and bolted together. They were towed out to place between two barges, the stone foundation laid roughly on them and grouted. When the crib rested on the bottom, the masonry was far enough above the water to allow stone to be set. The cribs were perhaps 12 ins. larger than the masonry all around.

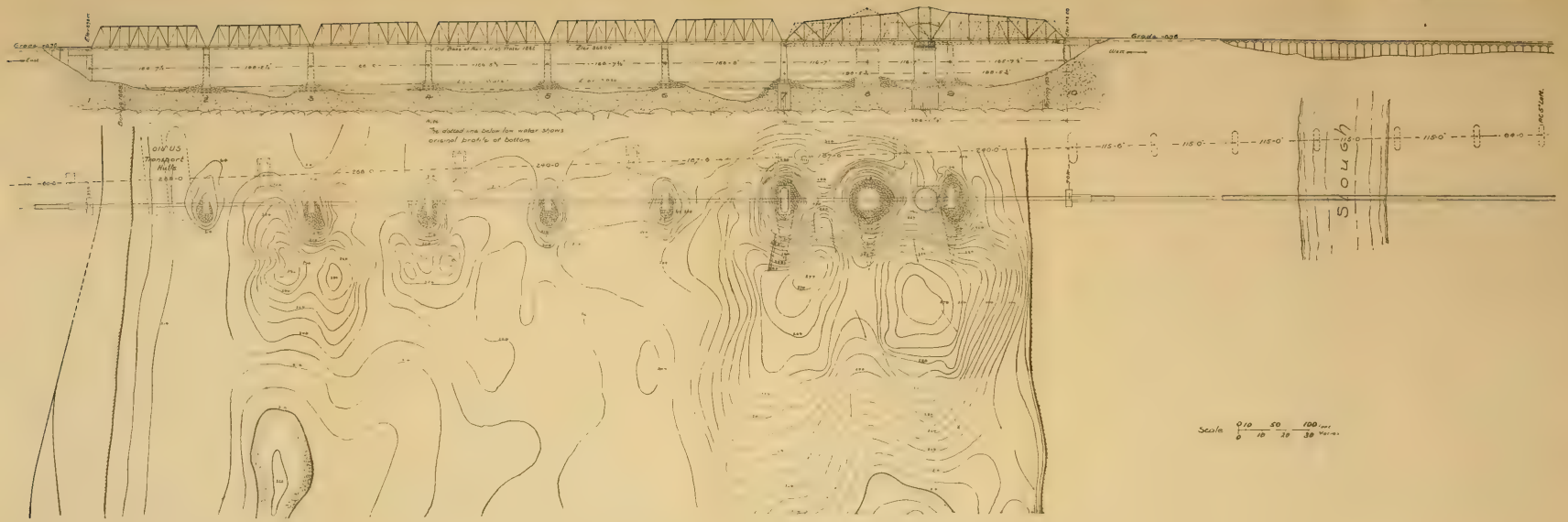
"In my report on the subject of the foundation of the bridge I protested against building the piers without going down to solid rock and disclaimed responsibility for undermining by water.

"The abutment on the east side is founded on rock. I was told by the Chief Engineer that the company was not willing to go to the expense of sinking coffer-dams down to solid rock."

Mr. J. R. Bryan, Superintendent of Bridges on this division, who was employed as a carpenter in the preparation of the foundations of piers Nos. 5 and 6 (see Plate XXVI), in a report to the Chief Engineer dated March, 1890, describes the work done in about the same manner as Mr. Ball, except that a floor was laid on top of the crib to receive the masonry and that the cribs were not filled with stone.

With regard to the condition of the bridge at the time of making the report he says:

"Pier No. 7 has settled and the top has moved toward the round pier 1 ft. 7 ins., the pier being plumb on the west side. Two hundred car-loads of rock have been thrown around this pier. In the rise of 1882, a large log house lodged against pier No. 9, and it settled eastward about 4 ins., down stream 8 ins., and vertically about 3 ins. When


Grade 1025
Grade 1025
Dotted line below low water shows original profile of bottom
SLOUGH
Scale 0 10 20 50 100 Feet

the water fell it showed that five large stones at the north end of the pier at low water-mark had fallen out. These were replaced by the company's masons, and under the direction of the Chief Engineer cribs constructed according to sketch (Fig. 1) were sunk on the down-stream

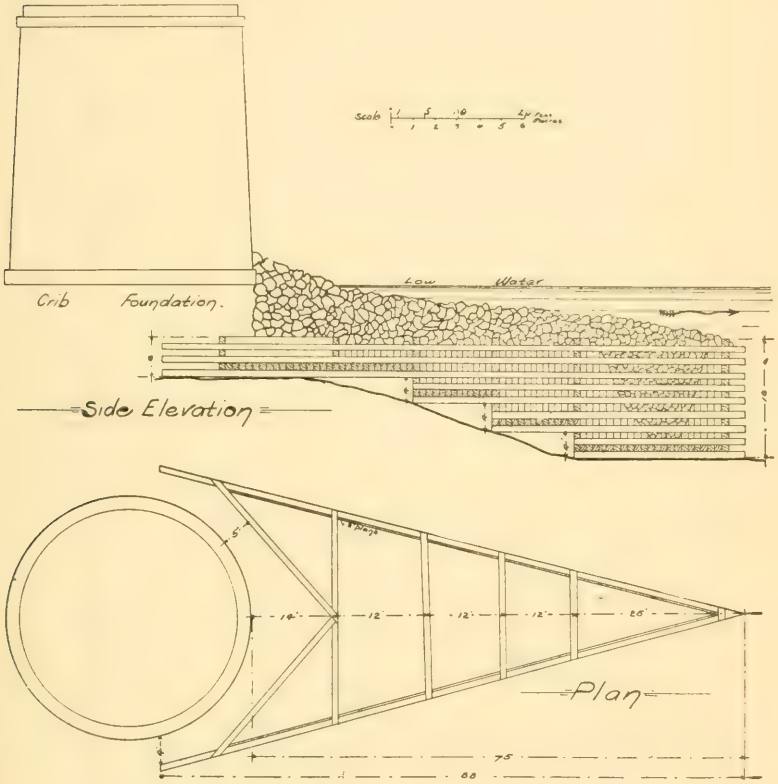


FIG. 1.

side. One hundred and fifty car-loads of rock and slag were thrown around it. Since then the pier has settled 1 in. eastward, and 2 ins. down stream. Similar cribs were sunk at piers Nos. 7 and 8. Pier No. 8, the round pier, has settled down stream about 4 ins. At the lowest water-mark a few inches of the timber in the cribs of all the piers is exposed to view. Up to date 843 car-loads of rock have been thrown around all the piers."

In 1871, the Nashville, Chattanooga and St. Louis Railway acquired control of the Nashville and Northwestern Railroad, and Col. R. C.

Morris, M. Am. Soc. C. E. (deceased), took charge of the bridge. In a report on its condition in 1890, he says:

"Unmistakable evidences of settlement were visible in 1871. A small island of gravel below the draw was then visible which has been increasing to the present time and now contains 5 acres above low water. A few years later another island was visible at low water near the east side and now contains ¼ acre. The round pier was pointed in 1871, 300 barrels of grout poured into it and bands put around it to prevent further spreading.

"On February 25th, 1890, spans Nos. 4–5 and 6–7 were blown away by a tornado. The spans were staged with piles at once, although the river was quite high (see Hydrograph, Fig. 4), and new spans put in, built on the same plan as the old ones, except that the floor-beam haugers and suspenders were strengthened and the lateral system rearranged."

Continuing, he describes the condition of the bridge and foundations, urges immediate action and presents plans and estimates for a new structure to be built just above the old one and estimated to cost $485 000. This bridge was to consist of two 60-ft. deck girders, two 268-ft. river spans, two 240-ft. river spans, one 375-ft. draw, twelve 115-ft. and one 94-ft. shore spans. The shore piers were to be made of iron shells filled with concrete and founded on piles. The river piers were to be of masonry, founded on pneumatic caissons. The proposed bridge is shown in dotted lines, just above the old bridge on Plate XXVI. This plan was approved by the management, and an agreement entered into with the Government to complete the new bridge and remove the old one by November 15th, 1894.

On account of continued decrease in earnings, the letting of the work was postponed from time to time, and at the time of the death of Colonel Morris, in November, 1892, nothing had been accomplished.

On November 8th, 1892, the writer was appointed Chief Engineer. The financial condition of the country and the physical condition of the bridge had both reached a serious point. The process of undermining the piers was going steadily on, and the islands below the piers were growing constantly larger by the addition of gravel from the scoured places.

Since 1879 the writer has been a close observer of the condition of this bridge, making frequent soundings to determine the depth and scour. The contours of the bottom, shown on Plate XXVI, are the result of soundings made in the fall of 1893, except those above con-

tours 311 and around piers Nos. 7, 8 and 9, which are from soundings made in 1892, before any dredging had been done around these piers.

The holes below the piers are deeper than they ever were before, but in previous soundings the depth varied, being sometimes 8 or 10 ft. shallower than the year before. The deepest scours appear after the heaviest floods, when the current attains a velocity of about 5 miles an hour, and during a season of light rises the holes appear to fill up. The islands, however, never get smaller. The gravel, which in light rises is washed from above and around the piers into the holes below, is again taken up and held in suspension by the heavier rises and stronger whirlpools formed below the piers until deposited on the islands below.

Steamboat men had for years been complaining of the narrowness of the channel and the danger to boats in passing through the draw. The Government, in order to compel early action in the matter, had ordered that no more riprap be placed in the river at that point and was prepared to enforce this order by indictment under recent acts of Congress, making such offences punishable.

The heavy expense of the proposed new structure and the time required for its completion put it beyond consideration, and a cheaper solution of the difficulty was necessary. It was apparent that the heavy scour around the draw piers was caused by the contracted channel, the scour around the other piers being comparatively light, except around pier No. 3. The channel here is contracted by a number of old United States transport and gunboat hulls, strewn along the east bank above the bridge, which were sunk by General Forrest with his artillery on the opposite shore during the late war.

Careful observation has failed to discover any settlement in any of the piers except Nos. 7, 8 and 9. Believing that if a good channel were provided for boats on the west side, no objection would be raised to riprapping or sinking mattresses around the other piers, and that the widening of the channel on the west side would decrease the scour around the other piers, it was decided to hold all piers east of No. 7, to strengthen, as far as possible, the old superstructure, and to put in a new draw at the west end.

It was considered inadvisable to found the new piers on gravel so near the large holes that had scoured out nearly to the rock, and therefore it was decided to found them on bed-rock. The question of

how close to the old piers the new ones could be placed was carefully considered by Col. Morris in his investigations. Opinions were sought by him from other engineers with the following results. One of these said:

"Material is sometimes disturbed 100 ft. from caisson during sinking. I would locate piers at least this far, if possible."

Another said, "Under favorable circumstances, I will be willing to go as close as 15 ft. to the old pier, provided that I can guard against danger by driving piles to support the ends of the spans resting on the pier. I would prefer, however, to keep 25 ft. or more away, as I could secure the safety of the old pier at that distance with less trouble and expense."

Another said, "I would advise, in sinking your piers, to get them at least 25 or 30 ft. from the foundation of the old piers. In the first place, sinking through rip-rap will be troublesome, especially as you will encounter more on one side of the caisson than on the other, and, if possible, you should be far enough away to avoid striking the rip-rap at all. Another reason is, that owing to the weight of your present pier, if you were to sink very close to it the pressure would be unequal on the caisson, and it would have a tendency to move away from the pier."

Realizing that to disturb the round pier meant an early stopping of navigation, and that, even if pier No. 9 was disturbed, the span could be carried either on trusses up and down the stream, or on piles, the arrangement of spans shown on Plate XXVI was recommended, and on February 23d, 1893, was ordered carried out.

The approval of the Government was secured, the agreement for a new bridge annulled and a new one entered into, providing for the completion of the new draw on January 1st, 1894.

Before asking for proposals, borings were made near the sites of the new piers in the following manner: A pile-driver with short leads was run on the bridge and old 6-in. Phœnix columns were driven as piles, being coupled in 30-ft. sections by means of eight iron straps, bolted through the holes left by the rivets, which were cut out. As this iron pile was driven down, the inside was pumped out with an iron-valve bucket. Previous borings at the shore indicated that rock would be found at elevation 272. Before the lower end of the pile had reached this elevation it became impossible to lower the gravel and sand inside the column on account of the upward flow caused by the pressure from without. It was then decided to drive the column

down without pumping out. This was done, and the lower end appeared to stop at a point 6 ft. below the elevation at which rock was expected. Being suspicious of this, a 5-in. wrought-iron pipe was pumped down inside the column, and rock was found at elevation 275. The cause of the difference was revealed when, on landing No. 9 caisson, one of the flanges of the column, which had been driven quite close to the edge of the proposed caisson, was found turned up under the cutting edge. The other column was driven to rock without trouble.

The plan contemplated the sinking of two foundations to bed-rock for the new pivot pier and pier No. 7, the tearing out of the masonry of Nos. 7, 8 and 9; the dredging of the channel to a depth of 8 ft. below low water, the carrying of the old spans while work was in progress, the erection of the new draw, the removal of the old draw and one fixed span, the renewal of all wooden truss members in the old combination spans, except spans Nos. 4–5, 6–7; the placing of equalizers under all cross-floor beams on the old spans, putting in heavier pier boxes, putting in new floor-beam hangers and suspenders on all the old combination spans, except 4–5 and 6–7, the rearrangement of the lateral bracing and the raising of the entire bridge 4½ ft. to get above the high water of 1882.

Proposals were invited for the work as a whole and in four parts, the foundations, the masonry, the superstructure of the new draw and repairs to the old bridge.

A plan for carrying the spans resting on pier No. 7, by means of lateral trusses 60 ft. long, resting on temporary pile piers, was suggested in the invitation.

Contractors were required to furnish plans for the foundations proposed and the manner of carrying the old spans while sinking was in progress. The pneumatic process of sinking was proposed, but others, such as dredging through open wells, would be considered, if accompanied by sufficient evidence of proving successful.

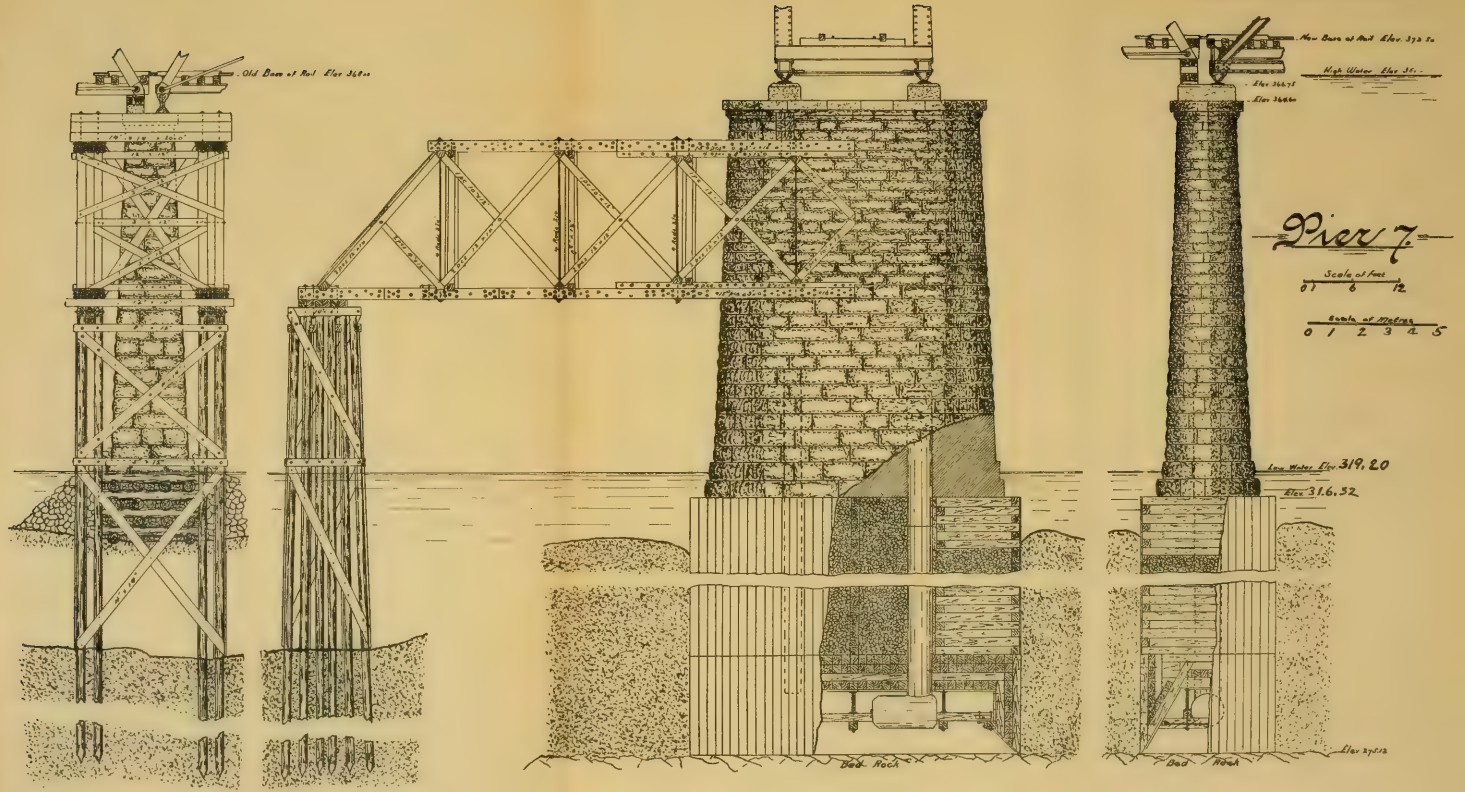
On April 28th, 1893, the work of substructure and masonry was awarded to the H. S. Hopkins Bridge Company, and the entire superstructure to the Louisville Bridge and Iron Company, both the lowest bidders.

The plan for carrying the spans and the caissons and cribs were substantially as shown on Plate XXVII.

The pivot pier caisson was 36 ft. square and 16 ft. high, and the one for pier No. 7 was 40 ft. 6 ins. by 16 ft. 9 ins. and 12 ft. high. Cribs filled with concrete rested on the caissons and extended to within 2 ft. of low water. All were designed by Mr. Frank D. Moore, Vice-President and Engineer of the H. S. Hopkins Bridge Company. The details of the caissons and cribs were practically the same as those designed by Mr. Moore for the Quindaro Bridge, described by him in his paper published in *Engineering News*, April 4th, 1891, the principal points of difference being that the sides of caissons were plumb, the abutting timbers lapped alternately, instead of being halved and lapped, and a steel shoe was used on the cutting edge. Mr. Moore gave the work his personal supervision from its beginning until the masonry was nearly completed.

In June Mr. J. H. Pope was placed in charge of the work as Resident Engineer, and remained until the completion of the contracts. In July W. H. Gahagan, Assoc. M. Am. Soc. C. E., took charge of the work as superintendent for the contractors. J. M. Johnson, M. Am. Soc. C. E., President and Engineer of the Louisville Bridge and Iron Company, designed the new draw-bridge, and Mr. John E. Gould had charge of the erection.

In order to secure the safety of the draw against floods, it was decided to sink the pivot caisson first, the contractors believing it more economical and safer to sink only one at a time. Believing it impossible to sink the pivot caisson so close to old No. 9 pier without endangering it, it was the intention to erect the carrying spans at No. 9 first, and take it down before sinking began. The plan was objected to by some of the members of the contracting firm as too expensive and unnecessary. Accordingly it was agreed that if piles could be driven close to No. 9, on each side to bed-rock, that this should be done and the spans supported on them. The experiment of driving one pile was to be made before starting others, but contrary to this agreement, eight piles were started down on the west side and each driven about 6 ft. That night, about 12 o'clock, the pier careened, the top moving westward about 4 ins. and down stream about 1 in., buckling the bottom chord of span 9–10, and displacing the lifting gear of the draw. The pier was now plumb in the axis of the bridge. It was deemed unsafe to experiment further in this direction, and accordingly steps were taken at once to erect the carrying spans as first proposed.


Old Base of Rail Elev 368.0
New Base of Rail Elev. 372.0
High Water Elev 361.
Elev 364.75
Elev 364.60
Pier 7.
Scale of Feet
0 1 6 12
Scale of Metres
0 1 2 3 4 5
Low Water Elev. 319.20
Elev. 316.52
Bed Rock
Bed Rock
Elev 297.12

This was done, and the old pier taken down nearly to low water before sinking was begun, on August 15th.

Fearing that the weight of the old pier and the sloping rip-rap would tend to displace the caisson eastward, it was started 1 ft. too far westward. Notwithstanding the fact that the rip-rap had previously been partially leveled by means of a weighted toothed drag scraper, the caisson had moved to a point 1 ft. too far east before its east edge had begun to penetrate. Shores were placed between the caisson and the round pier, and a heavy bank carried under the west cutting edge. In spite of all efforts, when the caisson was righted up on the rock, the top was found to be 1½ ft. too far east.

When the cutting edge reached elevation 287, the masonry was begun, the weight of the finished crib being insufficient to sink it further. The first course of masonry was set within 6 ins. of the west edge of the crib, the original plan being to place it 2 ft. from the edge all around. When the cutting edge was landed and the masonry leveled, the pier was found to be exactly in position east and west, but 2 ins. too far up stream. This was corrected as the masonry was built up, and the top was finished in exact position.

After penetrating all the rip-rap at elevation 299, nothing but gravel and sand was found until elevation 291 was reached. Here a 4-in. stratum of river gravel was reached, closely cemented with sand and iron. Fragments of this stratum are to be found in many places on the island below. Nothing else but gravel was found save a 4-in. stratum of blue clay directly on the rock. Measurements taken from the water at the four corners showed the rock to be level.

The sinking of the caisson had disturbed the gravel around it very little. Nearly all the false-work piles used in the erection of the carrying span were left erect, only the four piles between the caisson and the old pier showing any signs of disturbance, these leaning slightly towards the caisson. None of these piles had penetrated more than 15 ft.

As soon as the caisson was landed piles were driven between the carrying trusses, forming a pier to carry the old spans. The supporting trusses were then removed to the site of pier No. 7 and re-erected. It being apparent that the trusses were longer than necessary, and they having sagged under their former load on account of the rough framing and shrinking of the green gum timber in the chords and angle

blocks, and the piles previously driven for the piers having found so little footing on account of the deep scour, it was decided to shorten the trusses before erection by taking off the end panels. New piers were then driven and the shortened trusses erected thereon.

As soon as the weight of the old structure was transferred to the trusses, the old pier was taken down. A steam dipper dredge was put to work clearing away the rip-rap and old cribs, which was done with little difficulty except that the space for handling the dipper was limited by the trusses.

The cypress and poplar logs taken out of the crib floated off as they were released. All the timber was sound. There was no flooring found on top of the crib, and the logs were, with few exceptions, round, being notched and drift-bolted at points where they crossed. The sinking of this caisson and completion of the masonry was quickly accomplished. Little rip-rap was encountered, the dredge having removed nearly all within the limit of the caisson. The stone was set between the trusses by means of a traveler at the level of the top chord of the old bridge, which took the stone directly from the cars standing on the bridge. This occupation of the track, interfering with the erection of the superstructure, necessitated a great deal of setting at night. Some heavy freezes occurred before this masonry was completed, and some of the stones which had been lately quarried cracked before being set. Others were substituted for them. No stone ever cracked after being set, and all are perfect at the present writing. This stone has since been adopted by the Government engineers for locks on the Cumberland River improvement. It is Niagara limestone and was taken from the quarry at Newsom on this division of the Nashville, Chattanooga and St. Louis Railway.

The concrete, composed of crushed limestone, 5 parts, screened Hollow Rock sand, 2 parts, and Louisville cement tested by Mead & Shaw, 1 part, was mixed on the shore, hauled out on hand cars, and dumped through chutes hung to the bridge by ropes. The fall of concrete was directed to any point desired by means of hand lines attached to the chutes. Little ramming was required.

The pressure-house was placed on the shore at the end of the bridge and connected by pipes with the caissons. Turning the draw did not interfere with the pipes to the pivot pier, and as pressure was not put on No. 7 caisson until after navigation was closed, there was no trouble here either.

Up to the time of the completion of the pivot pier, navigation through the draw had not been interfered with, but on October 20th the removal of the old draw began and the traffic of the river was transferred from boat to boat by locking them together under the bridge.

Span 9–10 had already been staged and removed. The west end of the draw was raised first, by a traveler working from the center, the staging and removal of the old draw going forward also. The east arm was then raised and the draw turned for boats on December 4th. It will be remembered that the base of rail of the new draw was to be $4\frac{1}{2}$ ft. above that of the old one. The trusses of the draw were erected in their true positions on the new drum, the cross-floor beams and bottom lateral bracing being left out entirely. The track on the bridge was then raised on the false-work to the new grade and the floor system put in, the approaches, including the two nearest spans of the old bridge, being raised at the same time. The traffic of the railroad was kept up continuously, no delays of any note occurring.

It being important that the removal of the old pivot pier should be completed before the river rose, as soon as the east arm of the draw was connected and before the track was raised and the floor system put in, temporary floor beams of wood were swung from the bottom chord by means of U-shaped hangers made of 3-in. round iron passing through 12 × 12-in. sticks laid along the bottom chord and supported on blocks near the panel points, and the track, which had previously been blocked up on the old round pier, was carried across it clear.

The removal of this pier was quite difficult at first, the grouting having proved very effectual for a distance of about 20 ft. from the top. Below this point the silt deposited in the piers by the frequent high waters had almost filled the voids, and, when not entirely filled, the coating of mud on the rocks prevented the cement from taking hold. The foreman who set the stone on this pier has recently stated that no mortar was used in it at all. The timber crib under it was found to be as above described. The dredging of this crib and the mound of rip-rap around it to a depth of 8 ft. below low water was finished and the whole substructure plant removed from the work by December 20th.

The strain diagram (Fig. 1, Plate XXVIII) shows the principal features of the superstructure. The total weight of the draw, exclusive of the turning engine and gearing, is 734 809 lbs.

The turning arrangement consists of two 8 × 10 reversible Atlas engines, with provision for turning by hand. The ends are raised and lowered by screw jacks, operated by a single wrench at each end.

The strain sheet (Fig. 2, Plate XXVIII) is of the old combination spans which still remain, the left half showing stresses produced by the loads for which it was designed, and the right half those produced by the loads now running over it, which from assurances received are the heaviest which will be placed upon it by engines for some years.

The timber in all the trusses, except those blown away in the tornado, had been in place since 1871, and it was feared that in spite of the careful housing some of it was rotten. This was all renewed while the masonry was being built. There was not a dangerous stick found under the housing, and all were in a remarkable state of preservation. The floor beams in these old spans were originally supported by castings carried on pins on the ends of the hangers and suspenders. It was impossible to adjust them, and the deflection in the floor beam caused the load to come almost entirely on the inside member. This was remedied by placing equalizers built of channels (see Fig. 3, Plate XXVIII) at the bottoms of the suspenders and hangers. Fearing that the continual bearing of the loads by the inside hangers and suspenders had weakened these members, they were replaced by new ones. The lateral system, which was very poor, was also rearranged, as shown on Plate XXVIII. The old spans were all raised to the new grade on timber blocking.

The railway completed the work of topping out the old piers. Bents were set up on each side of each pier, founded on rip-rap, and both spans carried on stringers thrown across the piers. The old coping was first removed, the walls built up and the coping put back. These spans are carried now as formerly on 2 ft. of timber on the tops of the piers, it not having been decided yet whether, when these spans require to be made heavier, new piers will be built or new metal spans be built on the old piers. All the old piers were carefully pointed in order that any settlement might be quickly detected. No cracks have so far appeared in any of the pointing.

All the iron work received one coat of red lead and oil before shipment, and after erection another coat of the same, with the addition of 1 oz. of lampblack to each pound of red lead.

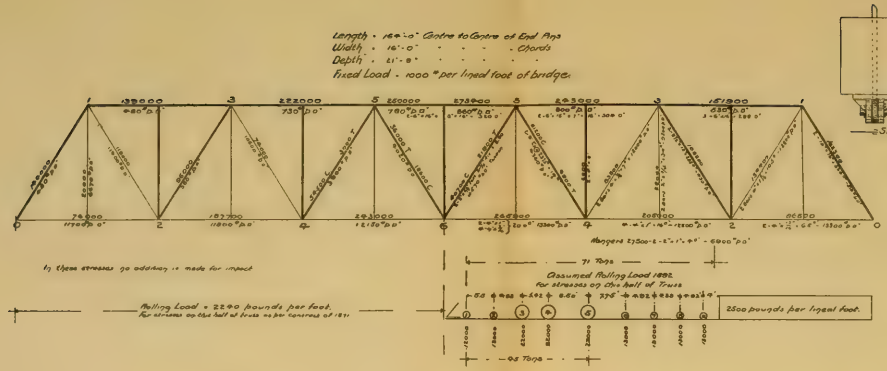

Length = 168'-10" Centre to Centre of End Pins
Width = 16'-0" " " " Chords
Depth = 21'-8" " " " "
Fixed Load = 1000 # per lineal foot of bridge.
In these stresses 30 addition is made for impact
Rolling Load = 2290 pounds per foot.
for stresses on the half of truss as per Cenvress of 1891
Assumed Rolling Load 1892.
for stresses on the half of Truss
2300 pounds per lineal foot.
71 Tons
65 Tons

FIG. 2.

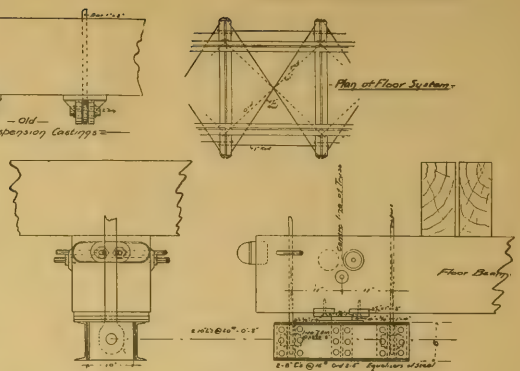


FIG. 3.

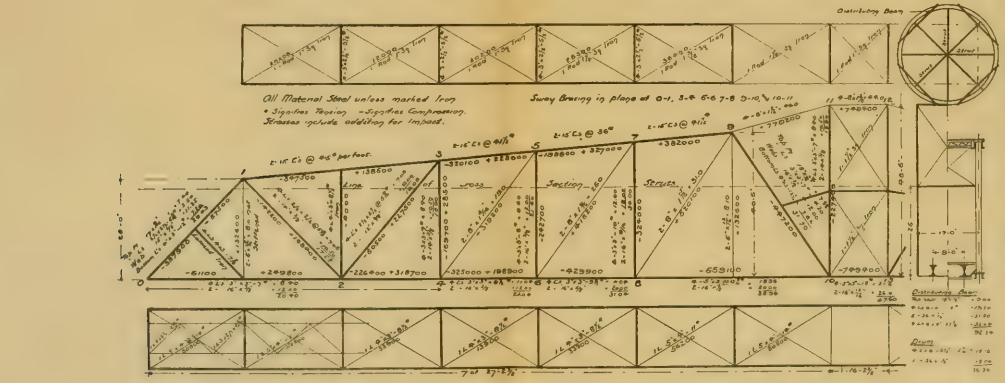


FIG. 1.

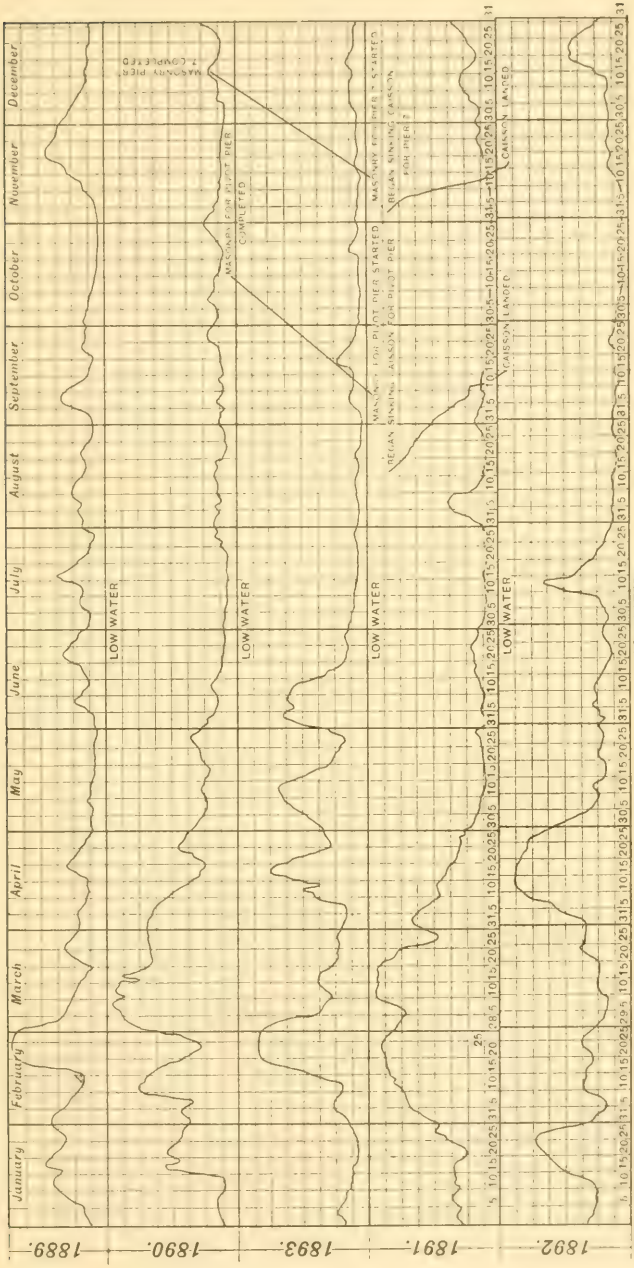
Length 386'-11 3/4" Centre to Centre of End Pins
Width 17'-0" " " " Chords
Depth 28-0 at ends, 40-6" at 8 40-6" at centre.
Fixed Load 2100 pounds per lineal foot of bridge.
Rolling " 2-150 tons Consols + 3500 # per lin foot

Stringers:		Floor Beam:	
Top Plate 12"-¾"	0.60	Top Flange 2-8½"-3½"@ ¾"	8.10
" Angles 8"-6"@18"-8"	8.90	Bot " 2-3½"-3½"@ ¾"	5.10
Bot Plate 12"-¾"	4.40	Web 98"-½"	1.8000
" Angles 8"-6"@18"-8"	8.40		34.20
Web 30"-½"	11.25	Cross Ties 8"-11"-13'-0"	
	37.25		

Dead Load - Entire weight of Truss + Floor. Timber 50 # per cu foot
Rails + Fastenings 80 # per lineal foot of track
Wind Load - 30 # per sq foot on exposed surfaces of both trusses and on moving train surface of 10 sq feet per foot of track applied 8 feet above the rail
Effect of Impact to be added to Maximum Stresses resulting from engine and train load by the formula —

$$I : \frac{S}{(300 + L)}$$

where S = Calculated maximum live load stress
I = Effect of impact
L = Length or loaded distance in feet



HYDROGRAPH.

NOTE.—Distance between horizontal lines = 5 ft.

FIG. 2.

The east approach was an embankment and was raised by filling. The west approach consisted of a short bank at the end of the bridge and a cedar pile trestle with five piles to the bent. Wherever the raise was less than 12 ins., it was accomplished by doubling the caps, but above 12 ins. additional brace piles were driven on each side at each bent, and the old piles spliced by setting blocks of cedar on them and cover jointing.

On Fig. 2, page 183, is shown the progress of sinking the caissons and building the masonry, also the stages of the water at this point from 1888 to the close of the work.

The cost of the entire work is shown in the following statement :

SUBSTRUCTURE.—COST OF PIVOT PIER.		
Caisson.		
119 792.40 ft. B. M. timber in caisson, at $38	$4 552 11	
95 727.50 ft. B. M. timber in crib, at $28	2 680 37	
54 975.00 lbs. iron in caisson in crib, at 4 cts.	2 199 00	
96.00 lineal feet shafting left in place, at $7	672 00	
44.00 lineal feet sinking below low water, at $344 81	15 172 42	
313.40 cu. yds. material removed through lock, at $35	10 969 00	
1 085.90 cu. yds. concrete in crib and pockets, at $6	6 515 40	
233.50 cu. yds. concrete in air chamber, at $12	2 802 00	
Cost of caisson	$45 562 30	
2 112 cu. yds. displacement, average cost per cubic yard $21 57		
Cost per vertical foot (44 ft.) 1 035 50		
MASONRY.		
415.62 cu. yds. face stone, at $12	$4 987 44	
725.19 cu. yds. backing, at $7	5 076 33	
24.52 cu. yds. coping, at $16	392 32	
Cost of masonry	$10 456 09	
Less credit old stone taken out	1 065 00	
Net cost of masonry	$9 391 09	
Total cost of pivot pier		$54 953 39
COST OF REST PIER.		
Caisson.		
54 950.00 ft. B. M. timber in caisson, at $38	$2 088 10	
60 097.00 ft. B. M. timber in crib, at $28	1 682 72	
40 964.00 lbs. iron in caisson and crib, at 4 cts.	1 638 56	
108.00 lineal feet shafting left in place, at $7	756 00	
44.08 lineal feet sinking below low water, at $217 01	9,565 87	
17.00 cu. yds. material removed through lock, at $35 00	595 00	
564.20 cu. yds. concrete in crib and pockets, at $6	3 385 20	
108.00 cu. yds. concrete in air chamber, at $12	1,296 00	
Cost of caisson	$21 007 45	
1 107.51 cu. yds. of displacement, average cost per cubic yard $18 96		
Cost per vertical foot (44.08 ft.) 476 35		

MASONRY.			
351.39 cu. yds. face stone, at $12	$4 216 68		
124.72 cu. yds. backing, at $7	873 04		
15.78 cu. yds. coping and pedestals, at $16	252 48		
Cost of masonry	$5 342 20		
Less credit, old stone taken out	535 00		
Net cost of masonry	$4 807 20		
Total cost of rest pier		$25 814 65	
REMOVING OLD PIERS.			
1 892.90 cu yds. old masonry removed, at $1 75.	$3 312 57		
3 393.30 cu. yds. removing old cribs and dredging, at $5 32	18 068 90		
Total cost		21 381 47	
Supporting old spans	$4 900 00	4 900 00	
Freight and passage (Company service)	$4 966 13	4 966 13	
REPAIR OF OLD MASONRY.			
Pointing, grouting and stone work	$4 630 83		
Supporting spans for topping out piers	826 38		
Total cost		5 457 21	
Total cost of substructure			$117 472 85
SUPERSTRUCTURE.—RECONSTRUCTION OF OLD SPANS.			
Raising and repairing old spans	$10 641 00		
Freight and passage (Company service)	117 95		
Total cost		$10 758 95	
NEW DRAW.			
New draw, erected complete	$36 948 00		
Freight and passage (Company service)	117 02		
Total cost	$37 065 02		
Credit, by old spans taken out	4 755 00		
Net cost of new draw		32 310 02	
Total cost of superstructure			43 068 97
Raising approaches—			
Trestle-work		$3 141 27	
Grading		808 61	
Total cost			3 949 88
Transferring traffic while navigation was closed:			
Cost of transfer track and moorings		$886 82	
Damage to steamboat companies		3 300 00	
Total cost			4 186 82
Engineering—			
Preliminary boring		$998 88	
Superintendence		1 177 75	
Inspection		358 10	
Testing		542 67	
Surveys and drawings		182 00	
Total cost			3 459
Switching		$1 522 27	
Total cost			1 522 27
Grand total			$173 660 19

Recapitulation		
Cost of substructure	$117 472 85	
Cost of superstructure	43 068 97	
Raising approaches	3 949 88	
Transferring traffic	4 186 82	
Engineering	3 459 40	
Switching	1 522 27	
Grand total		$173 660 19

DISCUSSION.

Mr. Macdonald. CHARLES MACDONALD, M. Am. Soc. C. E., remarked that the subject treated in the paper is one which recalls many similar experiences where much is required to be accomplished with very little money. In this case the results seem to have been very satisfactory and reflect great credit upon the engineer in charge. It is an unpleasant thing to note that the allowance for engineering should be put down in the detailed statement of cost as only 2% of the whole estimated expenditure. It is to be hoped for the sake of the profession that the time will soon arrive when the remuneration of engineers will at least equal that of architects for the work which they have to do.

There is one question which he would like to have more fully discussed by those who have had experience in the sinking of caissons, viz., the lateral movement of the caisson in sinking.

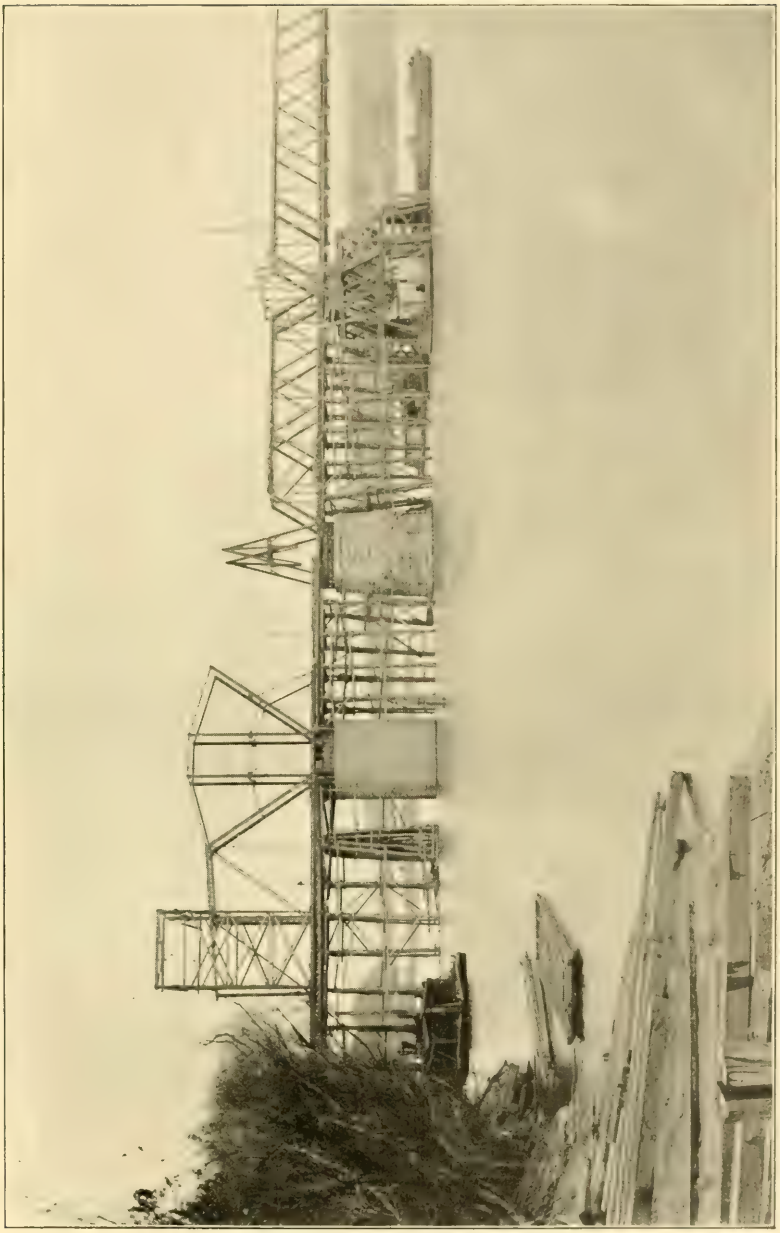
He understood from the paper that the caisson was set 1 ft. out of center to the westward, in order to provide for a possible movement to the eastward in sinking, due to an excess of rip-rap on the high side, and that, as a matter of fact, the caisson did move 2½ ft. to the east before reaching bottom.

In sinking Pier No. 6, Hawkesbury Bridge, by open dredging, a similar movement took place. At the site of the pier the bottom of the river sloped diagonally across the long axis, and the pier moved bodily in the direction of this slope.

The movement was finally counteracted by depositing 2 000 or 3 000 yds. of rock close to the pier on the low side.

Mr. O'Rourke. J. F. O'ROURKE, M. Am. Soc. C. E., said that the method employed to right the caisson at Hawkesbury, described by Mr. Macdonald, was precisely the reverse of that used to level one of the caissons of the Poughkeepsie Bridge, which were very large, measuring 60 x 100 ft. and 100 ft. high, and had two lines of dredging pockets.

These caissons, even after they were well down in the river-bed, had a tendency to rock, settling, perhaps, 3 or 4 ft. out of level, and, after they had been again dredged out and dropped, would tip the other way. It was then supposed that the high side penetrated deeper into the bed by virtue of the increased momentum gained in falling through a greater space. Accordingly the plan of removing less material from



under the high side was tried with caisson No. 5, which was 6 ft. out of level longitudinally and 3 ft. transversely, and when it was undermined sufficiently to move, it dropped 8 or 9 ft. In its new position it was only 0.4 ft. out of level longitudinally, and 0.1 ft. transversely. Mr. O'Rourke.

He thought the cause of the trouble with the pivot-pier caisson, mentioned by the author, must have been due to the fact that there was more rip-rap on one side of the pier than on the other. This would account for the movement, since in the case of rip-rap it takes place before the caisson is sufficiently embedded to hold it laterally.

The plan of simply lapping the timbers of caissons and depending upon drift bolts to hold them in place, was to be commended. The framing together of 12 x 12-in. timbers he thought a common mistake made by architects and engineers, and no more necessary than splitting bricks, to have them bond better at the corners of buildings.

In connection with the Poughkeepsie work, experiments were made to determine the adhesion of drift bolts in 12 x 12-in. timbers; 422 lbs. per lineal inch for 1-in. round bolts in $\frac{1}{16}$-in. holes was the minimum found, about 1 200 lbs. per inch being the average. It is therefore plain that an enormous force would be required to lift timbers fastened in this way, and still more would be necessary to slide them on each other.

T. C. Clarke, M. Am. Soc. C. E., in speaking of drift bolts, said, that in the original plans for the Poughkeepsie Bridge the caissons were designed before the Union Bridge Company took hold of the bridge to build it. They were then altered considerably. In the old plans all vertical timbers (some 25 or 30 sets) were to be drifted laterally in each course, in order to prevent the courses pulling apart. But as these vertical timbers were very awkward to connect in this way, and would take a great deal more time to build into the caisson, which was of wood, they were omitted; every course was put down horizontally in the water and without any cutting. Mr. Clarke.

It was necessary to ascertain what number and size of drift bolts would be necessary to prevent the buoyancy of the timber from floating the caissons apart before being filled with concrete.

So the specimens at Athens were made, and the tests showed that they gave ample strength. These experiments and others have been described and published in the *Transactions* and elsewhere.

F. Collingwood, M. Am. Soc. C. E., remarked that he would like to add an experience had on the caisson of the Brooklyn Bridge. The conditions were like those described here; at the inner edge the material was very hard, but on the outside it was river mud, compressible although not soft. The caisson was kept level, but when hard bottom was reached at 42½ ft. depth, it was found to be 2 ft. out of position towards the river. The masonry up to high water had been laid abundantly wide, and the error was corrected on the next course of masonry. The movement was totally unexpected, and caused great surprise. Mr. Collingwood.

CORRESPONDENCE.

Mr. Johnson. J. M. JOHNSON, M. Am. Soc. C. E., stated that he had read this paper with a great deal of interest, as it deals with a structure similar to quite a number constructed south of the Ohio River 25 or 30 years ago. The style of foundation then in vogue, as described by the author, was delightfully simple, and only a special Providence, supplemented, however, by a liberal and early use of stone by the railroad company forming loose revetments around the base of each pier, averted disaster.

He agreed with the author's conclusion, that as a service extending over 30 years has developed no appreciable settlement in piers Nos. 2, 3, 4, 5 and 6, the removal of the obstructions due to the old round pier and pier No. 9, with additional revetment at the base of each pier, will render these foundations safe. The additional revetment would in his judgment be advisable, to prevent scouring due to accidental causes. The difference between extreme high and low water of the Tennessee River is about 50 ft., and, at times of flood, immense trees are carried with the current, which, lodging against bridge piers, oftentimes cause a scouring of considerable extent, and that, too, in a remarkably short space of time.

The new superstructure possesses no points of more than ordinary interest or special construction.

The problem of erection, however, was more difficult. The old superstructure was to be removed, the grade raised 4½ ft., and traffic not to be interrupted. The grade was raised gradually on the false-work over the new draw span, long "run-offs" being made at each end, until the maximum of 4½ ft. was attained, with but slight delays to trains.

As time was an important consideration, it was necessary for the old spans to be removed and the erection of new superstructure commenced before the completion of the masonry. He remarked further, that with two sets of men, not serving the same master, both anxious to occupy the track at all times between trains, the question of the proper time allowance to each was no doubt a serious problem to the Chief Engineer of the railway company. The rapid and successful completion of the work sufficiently attests the satisfactory solution of the problem.

Mr. Dunham. H. F. DUNHAM, M. Am. Soc. C. E., called attention to the sketches of Pier No. 7, where timbers are shown bolted to the piles at a depth of 12 or 15 ft. below low water, for the purpose, evidently, of increasing the stability of the group or cluster, and stated that a more usual, if less painstaking, method would be the selection of piles of such diameter and number that when driven they would carry the imposed load from the surface of the water to the bottom of the river without buck-

ling. Then the lateral stability of the temporary structure could be increased, if necessary, by driving piles a few feet away upon either side and drawing the heads at about low water level up to the cluster and bolting them there. He thought it would be interesting to know the actual cost of placing the 4 x 14-in. timbers at that depth below low water and whether it was necessary to employ a diver for any other purpose during the construction of the work. Mr. Dunham.

Hunter McDonald, M. Am. Soc. C. E., in closing the discussion, agreed with Mr. Macdonald that the charge to engineering constitutes too small a percentage of the total cost, but stated that this is not an unusual case, which fact is generally due to causes beyond the control of the engineer in charge, and that the remedy for such a state of affairs can be found only in united action by the various engineering societies. The regulations of the Inter-State Commerce Commission, for the classification of operating expenses, require that salaries of all general officers be charged to one item; otherwise the percentage of engineering in this case would have been larger. Mr. McDonald.

He considered that there was little danger of any trouble from the timbers of the caissons parting on account of buoyancy, as green oak and gum were used exclusively. Besides this, the outside of the caissons was made of vertical timbers, and the alternate layers forming the tops of the caissons were securely bolted to the outside verticals, besides being heavily drift-bolted, each to the other. Vertical planking on the outside of the cribs prevented any parting of the horizontal timbers in the same, by reason of friction or buoyancy.

He further stated that the lateral movement of the caisson of the pivot pier was due to the fact that it began to penetrate on one side first and to the heavy weight of the old pier on the high side, and that until the entire cutting edge began to penetrate, rip-rap would have been ineffectual to prevent lateral movement. The immense quantity which would have been required on account of the adjacent deep holes made this method impracticable.

There was a difference of opinion among those connected with the work as to the effect of lapping the timbers on the stiffness of the caisson. Unless the halving and lapping is done with great precision, he thought the other plan the better, and that the results gained by the former plan do not justify the expense.

He added that the bracing of the piles under the water was considered necessary on account of the likelihood of the gravel scouring from around them and from the fact that steamboats, rafts and other floating bodies might strike the piled piers with great force. The piles driven were selected large ones, and the bracing was an additional precaution. A diver was constantly employed, who, when not working under water, worked above. The expense was comparatively small, although the exact figures cannot be given.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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745.

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WIND BRACING IN HIGH BUILDINGS.

By GUY B. WAITE, Assoc. M. Am. Soc. C. E.

READ DECEMBER 19TH, 1894.

WITH DISCUSSION.

There is nothing that seems more important in architectural engineering at the present time than a thorough consideration of the lateral forces to which any of the very high modern buildings may be subjected, and a practical and uniform agreement on the proper system of treating the structures to resist such forces.

On the question of safe construction for positive vertical dead loading there is substantially no disagreement among engineers, and the proper allowances which it is advisable and wise to consider for superimposed vertical loads on floors in such buildings are generally agreed upon, although it is conceded that such loading may not occur more than once in a decade.

After taking into account the nature and the value of the various live forces, which act vertically, horizontally or otherwise, the question naturally presents itself, whether modern buildings are being constructed with the same amount of safety against all of the various

forces mentioned. Certainly no one will question the wisdom of insuring a structure against each of the destructive forces to which it may be subjected, to a degree at least proportionate to their probabilities.

Most designers of high buildings are convinced of the safety of their structures against the ordinary forces which will be brought to bear upon them, but they do not always base their conviction upon scientific reasoning, and therefore it is natural to find a diversity of design proportional to individual opinions.

All engineering designs for high structures, such as towers and chimneys, are made to conform to mechanical principles for the resistance of lateral forces of wind at a pressure of from 25 to 50 lbs. per square foot of exposed windward surface.

While the sizes of building lots in the large cities are not materially changing, the heights of the buildings placed on them are rapidly increasing; so that now numerous buildings extend 250 ft. above curb level, and there are many instances of buildings varying from 23 to 25 ft. in width and from 120 to 175 ft. in height, with the uppermost 100 ft. exposed to wind. Now, from a scientific or engineering standpoint, structures with sections corresponding to the last mentioned should at least have positive resistance, and if the construction is of a character to permit doubts as to its ability to perform a particular function, such doubts should be on the side of safety.

Observers will have noticed examples of buildings having cross-sections corresponding to the latter dimensions given—from 80 to 100 ft. deep and almost identical in character and general planning—where one structure is made to depend upon cross partitions, end walls and the ordinary girder connections, with columns for transferring horizontal forces to foundations, while the other has a distinct system of structural bracing capable of caring for similar forces. It would seem that either one owner was put to unnecessary expense, or that the other has not proper insurance on his structure. In doing justice to the subject, however, it may be said that partitions, walls, etc., as ordinarily constructed, cannot be relied upon to act in conjunction with steel structural work in resisting lateral forces, and, therefore, if the former means can be relied upon in a certain case, there will be a limit beyond which the steel frame must take up such forces, and then we could have examples similar to the one above described.

where one building is within the limits for resistance by partitions, walls, etc., and the other one just beyond that limit. Such a classification can, however, be made properly only after the qualifications of the materials for resisting such forces have been definitely determined, in order to place them on a footing with steel structural work.

Dr. Draper, who is in charge of the Meteorological Bureau at Central Park, recorded a wind pressure of 49¼ lbs. per square foot on November 12th, 1883, at 7.30 P.M.; 36¼ lbs. per square foot on March 12th, 1888, at 2.15 P.M.; and 44 lbs. per square foot on January 30th, 1894, at 3.15 P.M. On October 10th, 1894, at 4.30 A.M., he recorded 21¾ lbs. per square foot from a northeast wind. This was about the time that a building under construction at No. 74 Monroe Street, New York, collapsed. The height of his pressure gauges is only 53 ft. above the surface of the ground, and the protection from surrounding objects necessarily causes pressures much less than would obtain for higher altitudes. The velocity-recording gauges of Sergeant Dunn, on the Equitable Building, give very much greater average records than Dr. Draper's. For instance, during the storm of October 9th and 10th, Dr. Draper recorded an average maximum velocity of 24 miles per hour, while Sergeant Dunn recorded a corresponding velocity for the same wind storm of 48 miles per hour.

The maximum pressures are of very short duration, usually not lasting longer than a second, but sometimes occur at intervals, and thereby tend to set up an oscillation in structures which they are capable of influencing.

After consulting standard authors, reliable data, and prominent engineers, the writer is unable to find any engineer who is willing to assume the responsibility of allowing an average of less than 30 lbs. per square foot horizontal pressure on the exposed windward portion of high buildings.

Since buildings of this class are not ordinarily subjected to horizontal forces other than wind, aggregating an approach to this limit, subsequent discussion will be confined to wind pressures only.

An argument often presented by those who are sanguine about the efficiency of ordinary materials of construction (such as walls, partitions, and general filling-in material) is, that the maximum pressures are simply local gusts of such short duration that their impulses are absorbed in overcoming the inertia of the mass. If this be true in very

high buildings, where thickness of wall is inconsiderable compared with the exposed height, the material of the structure must act as an elastic body, and the wind impulses must be of such short duration that, before the reaction of the elastic mass has taken place, the force of wind has subsided, and the impulse has been exhausted in internal work. Now, if there should be a succession of such impulses and one should come not in harmony with the vibration created in the material, the heavier the mass the more detrimental would its weight become when its oscillation and the wind impulse act together. Furthermore, if the wind impulses are thus dissipated, the prevalent practice of calculating for vertical reactions due to them is erroneous; for no horizontal force on one side of the structure can cause a vertical reaction on the opposite side without being transformed by intervening construction.

The Venetian Building, in Chicago, which is 50 x 108 ft. and 135 ft. above curb, was designed for a total wind pressure of 40 lbs. per square foot. The steel construction was designed to take 70% of the total pressure, and the general mass of the structure was relied upon to take care of the remaining 30 per cent. It may not be unreasonable to assume that a building can be built so that the natural bracing of its general construction and the special bracing of the steel structure may accommodate each other enough to act in conjunction, in which case why cannot 40 or 50% of the entire pressure be taken by the general construction in more favorable cases? To formulate definitely for the various existing conditions, more complete data seem necessary such as—

First.—The maximum amount of wind pressure on good-sized areas at various altitudes, and under all ordinary circumstances, in the especial locality under consideration; also, the length of time during which such maximum pressures act.

Second.—Experiments on the strength of partitions, walls, etc., for resisting vibrations and thrusts under similar conditions to those existing in buildings.

Third.—Experiments to determine to what extent the mass of the structure directly absorbs the impulses of wind pressures.

Under present circumstances, there seems to be no reasonable course of procedure left for the discussion of existing conditions other than to accept authentic data and the judgment of the most experienced authors.

Under this conviction the writer will discuss some structures, the general dimensions of which are in accordance with plans coming under his observation. For the first example let us examine the construction of an ordinary non-fireproof building not classed with high structures. Take a warehouse building (Fig. 1), 23 ft. front and rear. 96 ft. deep, and 85 ft. high, located with an alley-way on one side and a three-story building on the other. Assume that the adjacent building

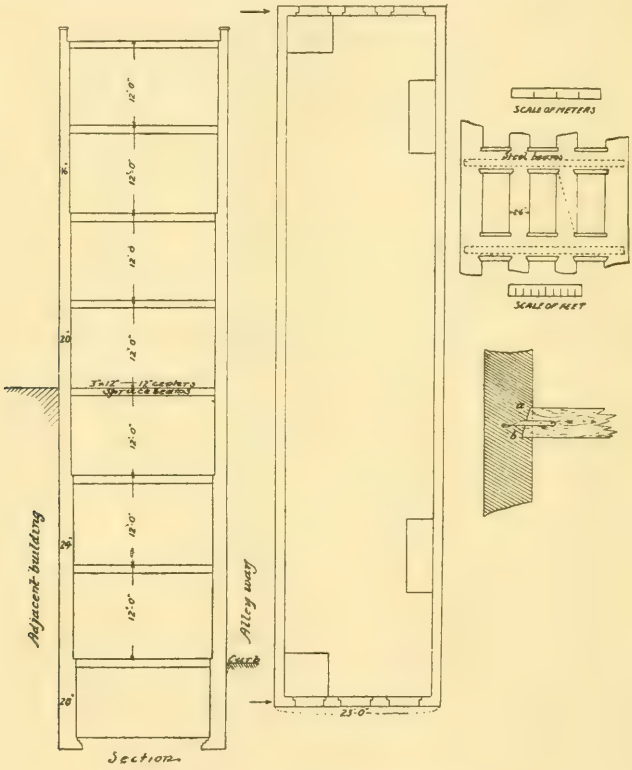

Fig. 1.

is capable of resisting the effects of wind when blowing towards it. and, for brevity, only discuss the effects which wind blowing on the exposed portion above the adjoining building will have on the structure.

The walls are of brick, 28 ins. thick in cellar, 24 ins. in first and second stories, 20 ins. in third, fourth and fifth stories. and 16 ins.

in sixth and seventh stories. First determine what wind pressure the dead weight of walls and floors will safely take care of. When the material in walls is not first class, the center of resistance at each joint is taken within the middle third (to avoid tension on the windward side); the dead weight above each floor level will resist the following wind pressures on the exposed surfaces above the floors:

7th	floor, 5	lbs. for	each wall	= 10	lbs.	
6th	" 3	"	"	= 6	"	
5th	" 2.7	"	"	= 5.4	"	
4th	" 2.15	"	"	= 4.3	"	Approximately.
3d	" 2.2	"	"	= 4.5	"	

As wind ceases at the fourth-floor level and the dead weight increases faster than the other functions as we proceed downward, 4.3 lbs., depending on the joint at the fourth floor level, will be the limiting wind pressure which can be cared for by walls and dead loads taken independently. Now, if the walls are of excellent material and well built, the center of resistance may be taken at one-quarter way from the inner side, which will make a maximum compression on the inside, of about 100 lbs. per square inch, and a maximum tension on the outside of 33 lbs. per square inch at fourth-story floor level; then the total limiting wind pressure which can be cared for by dead weight is 6.5 lbs. per square foot on the entire exposed surface above the adjacent building. This pressure corresponds to a wind velocity of 40 miles per hour. Now, for a pressure exceeding 6.5 lbs. per square foot, the surplus must be carried through the structure to the foundations, and we must look for means in the construction to provide for it.

The maximum shear from wind will occur where the aggregate effect comes on the fourth and lower floors. Then the next problem is to determine what wind pressure the fourth and lower floor systems are capable of transmitting from the horizontal to the vertical.

A wooden floor beam as usually laid in a wall, with beveled edge and not anchored, can exert no resisting moment at its seat; but if its back edge is built up solidly against, and it has a solid seat, and is well anchored in the wall, it can be relied upon to resist something.

In the present case the 3 x 12-in. spruce floor beams, spaced 12 ins. on centers, have every sixth beam anchored. Now, supposing that

such beams have been built into the wall with a view of exerting a resisting moment at their ends, and that they are anchored with straps with net sections of $1\frac{1}{2} \times \frac{3}{8}$ ins., and fastened on center line of beams with two $\frac{3}{4}$-in. spikes, we can allow for such resisting moment 6 000 in.-lbs. Such moment will resist a wind force on a wall 50 ft. high by 6 ft. wide (when considering the wall rigidly held at each floor level) of about $\frac{2}{3}$ lb. per square foot at each end of the beam, or a total of $\frac{3}{4}$ lb. per square foot. Had all beams been thoroughly anchored, they would have sustained a wind pressure of $4\frac{1}{2}$ lbs. per square foot. If each beam had been anchored by wall plates at both top and bottom, they would have resisted a total of 9 lbs. per square foot wind pressure on exposed wall. Thus far we have found a total resistance for structure as follows: walls, 6.5 lbs.; floor beams, .75 lb. = 7.25 lbs. This is equivalent to a velocity of 42.5 miles per hour.

This velocity will cover that of ordinary winds, but in a violent storm the velocity will reach 70 miles per hour on a building of this height located in New York City, with surroundings as described. That is equivalent to a total wind pressure of 20 lbs. per square foot, which should be provided for in a structure of this kind. This leaves 20 lbs. — 7.25 = 12.75 lbs. to be provided for in some part of the construction not yet considered. If floors are well constructed throughout, they, with the walls, will form a truss sufficient to transmit such a horizontal pressure to the ends of the building, where, if sufficient provision has been made in the fronts, it can be conducted safely to the foundations. We will assume in this case that fronts have three windows in each story, with piers 30 ins. wide between them; in the panels above and below the windows are two steel beams sufficient for all emergencies anchored into the wall at each end. Now, the girders over and under each set of windows, with the filled-in brick work between them, form a truss which must transmit the total shear at the fourth-floor level of 30 600 lbs. The girders by confining the brick work act in the capacity of ties, and the piers as diagonals in transforming horizontal pressures into vertical ones. We can assume that the stress is equally divided between the four piers, then we will have a resultant diagonal strain on each of 25 000 lbs. The pier being 20 ins. thick, and allowing 100 lbs. per square inch pressure, an active diagonal section of brick of 20 x $12\frac{1}{2}$ ins. will be required. Such piers

should properly be made of good hard brick laid in cement, to insure an efficient diagonal. The actual bearing area on the diagonal edges of piers may be quite small if of good material.

As the dead weight in the front greatly exceeds the vertical reaction, the latter will not be discussed here.

A practical illustration of the partial transmission of horizontal pressures to end walls by the floor system, and the resistance of such end walls to horizontal forces, can be seen in the buildings located at Nos. 250 and 251 South Street, New York City. The buildings are each about 24 ft. 6 ins. front and about 150 ft. deep, extending through from South to Water Street. There is a small break in the party wall at about 90 ft. from South Street of 1 ft., which slightly stiffens it.

No. 250 South Street is six stories high, or 65 ft. above curb. No. 251 South Street is five stories, or about 50 ft. high. Floor beams are 4 x 12 ins. spaced 16 ins. on centers, and each building has a row of columns and 10 x 12-in. girders. Columns are 8 ins. diameter, cast iron, for three lower tiers, and 8 x 8-in. yellow pine above, spaced 10 ft. on centers. The walls are 24-in. stone foundation, and 16-in. brick upper walls.

No. 251 South Street has only a one-story blacksmith shop on the east side, and is therefore exposed to northeasterly winds on the four upper stories. No. 250 South Street has only the upper, or sixth, story exposed on the easterly side.

No. 251 South Street is leaning westerly 5 ins. at the front and increasing in extent to about 30 ins. at central part. The foundation walls are in perfect condition, and no settlement of either has taken place. The easterly exposed wall has an appearance of being "scooped out," owing to the bottom part remaining nearly in line, while the upper part has yielded most at the center, gradually diminishing at the ends where it receives its support.

No. 250 South Street has yielded and leans similarly to No. 251, as also the three or four adjoining westerly buildings, but to a lesser extent, and it seems to be mainly due to the westerly buildings that the ones described are held in place.

Since the above was written, the sad details of the fatal wrecking of the new warehouse building in course of construction at No. 74 Madison Street adds another to the list of buildings collapsing by wind pressure.

The building was 20 ft. front, 92 ft. deep and seven stories, or 75 ft., high above curb level. The bearing walls were 24-in. brick foundation, 20 ins. through first and second stories, and 16 ins. thick above. The floor beams were spruce, 3 x 12 ins., spaced 16 ins. on centers. During the storm which wrecked the building, the maximum velocity recorded at the United States Weather Bureau on the Equitable Building for one hour was 48 miles, which would mean an average pressure of about 10 lbs. per square foot.

At the Meteorological Observatory in Central Park the maximum impulse (which lasted but one second) occurred at 4.30 A. M., and was 21¾ lbs.

The wind evidently caught the unfinished building nearly broad side, but at a sufficient angle to throw a considerable pressure against the leeward wall through the unfinished open front. The front portion of the building was completely thrown over down to the foundation, crushing the adjoining two-story frame structure, while the rear portion of the building was held up and stood after the wreck by means of the completed rear wall.

Not being able to determine the exact conditions at the time of the accident, the wind pressure which was required to collapse the structure cannot be determined.

For a second example, we will refer to a skeleton-constructed 17-story fireproof office building (Fig. 2), located on the corner of two streets with 32 ft. front, 100 ft. deep, and 194 ft. high above curb level. The long side not facing the street is protected from wind pressure by an adjacent building for 50 ft. above curb; and in order to be liberal in our considerations we will assume the adjacent building capable of resisting the thrust from wind pressure on the structure under discussion when acting against it. Then the maximum effects of wind on columns, girders and connections will be when it is blowing at right angles to the portion of structure over the adjacent building.

The maximum strain on girders, bracings and the connections, also the bending in columns, will occur in the floor system at the level of the adjacent roof and all tiers below it.

The maximum vertical reactions in columns and foundation will occur, of course, in the lowest tier of columns.

For the transmission of stress from horizontal to vertical members, we will assume that form of bracing which is readily introduced into

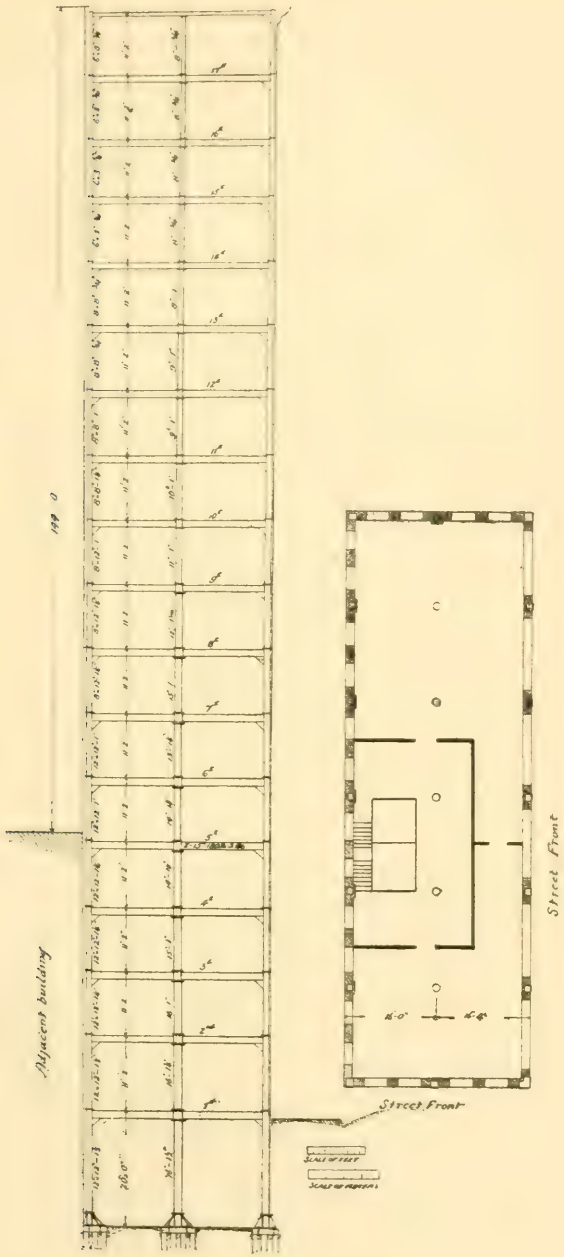

FIG. 2.

this class of buildings, consisting of knee bracing located at the juncture of the floor system with the columns. The dead weight of the walls and floors is conducted by means of supporting girders to the columns, and the amount of wind pressure which it will directly counteract depends largely upon the kind of column connection.

Suppose the 12 x 12-in. columns which connect at the fifth tier of beams have strong 3½-in. flanges, making the total width of base 19 ins., and allowing the center of resistance to come within 2½ ins. of edge of flange, the total resisting moments from the dead weight at the three rows of columns will counteract an aggregate wind pressure on the exposed surface of about 4 lbs. per square foot, which corresponds to a velocity of 31 miles per hour.

For the benefit of those who are sanguine about the efficiency of partitions and cross walls for resisting horizontal forces, assume that they have been especially built with that purpose in view. The partitions will seldom be located concentrically with reference to the center line of wind pressures, and their location will often vary in different stories, but the floor system with arches completed is capable of distributing the pressures, and their eccentricity need only be taken into consideration when it is so great as to permit danger of torsional movement.

Suppose the partitions are of 4-in. terra-cotta blocks laid in Portland cement and have doorways as shown in plans (the floor beams are assumed to be able to withstand the stress imposed by partitions when acting as braces without appreciable deflection), then we will have in principle a system of trusses with partitions acting as struts. On account of the tendency to side flexure, the allowable unit stress must be taken very small. Allowing 25 lbs. per square inch for partitions laid in cement 11 ft. high, the aggregate capacity of those in fourth story will resist a horizontal force of 10 000 lbs.

End walls have five mullions 20 x 20 ins., 8 ft. high, which will resist a horizontal force of 10 000 lbs. at each end wall at 100 lbs. per square inch, mean compression. Hence the capacity of partitions and end walls in fourth story aggregate a total of 30 000 lbs. horizontal force, or an average of a trifle over 2 lbs. per square foot of exposed surface. The total resistance thus far discovered provides for a wind pressure of about 6 lbs. per square foot, or a velocity of 38.5 miles per hour. Therefore, to provide for a velocity of 87 miles per hour, or a pressure

of 30 lbs. per square foot, the bracing provided in the steel structure must be capable of taking 24 lbs. horizontal pressure per square foot. The aggregate shear for 24 lbs. pressure at fifth tier of beams for one bay is 55 500 lbs. This will be equally divided among the three braced connections of columns and girders, so that the horizontal force to be transformed by each will be 18 500 lbs. In view of the uncertainty of cast-iron columns and their imperfect connections for resisting transverse loads, it is but fair to consider them as hinged at each

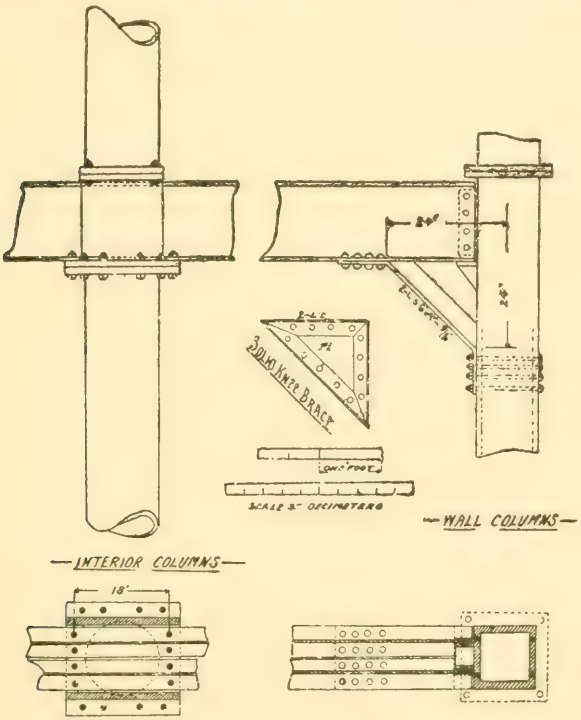

FIG. 3.

story in determining the stresses for knee braces, bending in columns, etc. By referring to detail it will be seen that the 18 500-lb. shear at the foot of fourth-story columns will cause a horizontal stress of 101 750 lbs. at foot of knee brace and an end reaction at girder connection of 83 250 lbs. The stiffener of the knee brace being at 45°, the stress on it will be 143 500 lbs. The bending moment from the braces on the floor girders will be 138 300 ft.-lbs.

The moment of resistance of the 12 × 12 × 1¼-in. cast-iron column being 175, the extreme fiber strain caused by the transverse load at foot of knee will be 11 400 lbs. per square inch at fourth story, and at all lower tiers having 12 × 12 × 1¼-in. columns. The direct dead load over second story is 470 000 lbs. on the 12 × 12 × 1¼-in. columns, and the aggregate live load at an average of 50 lbs. per square foot is 96 500 more. The vertical reaction due to 26 lbs. wind pressure will be 105 000 lbs.

Taking the dead load and the vertical wind reaction together on the leeward column in second story it will be strained by a direct load to 10 500 lbs. per square inch, and in fourth story to 9 000 lbs. per square inch. At the foot of brace, where the transverse load causes an extreme fiber strain of 11 400 lbs. per square inch, the metal will be strained to 21 900 lbs. per square inch compression in second story and 20 400 lbs. in fourth story, without considering the live loads which may be on the floors.

This amount is in excess of allowable stress on cast iron, and under the conditions it is believed to be too much for safety.

The connection of the top of column to the floor girder must be able to resist a horizontal force of 83 250 lbs., and the connections at foot of columns themselves must resist a shear of 18 500 lbs., not considering friction. The knee brace should have a section of two 6 × 4 × ⅝-in. steel angles riveted together, and with sufficient bolting to the columns and to the girders to take a shear of 101 750 lbs. The vertical reaction at seat of girder due to brace will be 89 000 lbs., and connections must be able to take the resultant of this amount and the 83 250 lbs. horizontal reaction with no load on floors. The same general conditions exist at the windward side as at the leeward, except that all moments are opposite in direction. With steel columns and rigid connections, making them continuous, and the knee brace with a substantial web sufficiently connected with column and girder to make all act as one piece, the point of contraflexure will be half way between lower column connection and foot of brace. The maximum bending in column will occur at foot of brace and at column connection, and will be 999 000 in.-lbs. If the column should have a moment of resistance of 175 (same as cast-iron column), the maximum fiber strain would be about 6 000 lbs. per square inch, while the strain on knee brace would be reduced practically one-half.

Considering the interior column hinged at base and the cross-girder connected to its top, as shown in detail (Fig. 3), the maximum bending from wind pressure in the column will be 2 000 000 in.-lbs.

The moment of resistance of the 14-in. diameter column, 1¼-in. metal, being 147, the extreme fiber strain will be 13 600 lbs. per square inch.

The dead load coming on the fourth-story column is 250 000 lbs., and the direct stress therefrom is 5 000 lbs. per square inch, or, assuming an average live load of 50 lbs. per square foot floor surface (in addition to dead load), the direct stress will be 8 000 lbs. per square inch.

This will cause a maximum compression of 18 600 lbs. per square inch in the first case, or 21 600 lbs. in the latter case.

The bending moment at the top of the column must be resisted by the connections of the girder to it; supposing the centers of girder bolts on the opposite sides of column are 18 ins. apart, the vertical reaction at each connection to girder flange will be 111 000 lbs., for which force the bolting must be made sufficient.

Buildings of this description should be provided with steel columns, and it will generally be found economical to increase the section where maximum bending occurs to take up the transverse loading.

In conclusion, the writer begs to refer to an instance of the yielding of a skeleton-constructed building to wind pressure. The building was 23 ft. front, about 85 ft. deep, and 125 ft. high above curb. It was protected from wind by buildings 60 ft. high on either side.

The structure was designed to resist wind pressures by means of front and rear walls and the special connections of cross-girders with columns. The constructor evidently did not consider the importance of these details, ignored them entirely, and, instead of utilizing the entire depth of girder, he gouged holes for fastening it to columns in the middle part of the girder webs. When the walls were up (except the top story) and the floor arches were yet to be put in the three upper floors, the building, during a wind storm, moved westerly from 8 to 10 ins., beginning at the roof of the adjoining westerly building and increasing to the top. The reason is evident: the building, under the force of the wind, had to move until the joints came to a firm bearing, and there it remained stationary.

The building was righted and made secure by elaborate knee bracing, made sufficient to take the horizontal force independently of the original connections.

The writer would call attention to the necessity of carefully executing the details of construction in structures of this character. Here the safety of the building will depend as much on the ability of the constructor as of the designer. Without the judgment to discriminate between vital parts and secondary ones, unnecessary work may be done in one instance or the structure may be endangered in another. The aim of the writer has been to present conditions rather than exact data, in order to encourage discussion which shall yield practical results.

DISCUSSION.

Mr. Clarke. T. C. CLARKE, M. Am. Soc. C. E., desired to know if the author disapproved of knee bracing, as he had said that he did not mean to advise any kind of bracing.

He wished to call attention to the fact of the presence of Mr. George B. Post, who had strongly expressed his opinion at the last meeting of the Institute of Architects as to the great danger of corrosion of iron and steel columns as applied next to outer walls of buildings, and to ask him if he is still of the same opinion.

Mr. Purdy. C. T. PURDY, M. Am. Soc. C. E., stated that the subject is one of peculiar difficulty on all sides, because the forces to be resisted are not agreed upon. The resistance of walls, either crosswise or lengthwise, is not definitely determined, and the same is true of partitions of all kinds. If more resistance is required than these afford, it must be provided in the metal frame, but so long as these first factors are uncertain, the work required of the metal bracing is correspondingly indefinite. The position of the bracing in the building and the method of its construction are also generally troublesome problems, and the strains are not always easy to determine. The stiffness of buildings is, of course, as important in small buildings as in large ones, but he could speak only of the latter, having had little experience with the former. It seemed to him that every pound of weight in a structure acts to some extent in resisting lateral movement, and that the equilibrium of the different parts of the building must be disturbed before there is any need of bracing. A well-made wall is not easily overturned crosswise, while lengthwise it acts as a brace. The conditions are not the same in any two buildings, and if any principles that will cover general conditions can be laid down, a long step forward will have been taken. Metal bracing must always be constructed in such a way that it will not interfere with either the appearance of the building or its usefulness. It is exceedingly difficult to do this in most buildings, and it is

very important that metal bracing should be tight in every connection, for if there is any play or movement possible between members, it cannot be very efficient. At various times he had found it impossible to use diagonal rods, and had substituted heavy plate work in the shape of portals. This construction has a great advantage in its riveted connections at all points, and it does not matter from which direction the wind comes—all of the metal is always in service. Mr. Purdy.

He further remarked that partitions are often omitted in steel-constructed buildings, and in his practice not much dependence is placed on their resistance to wind in regular office buildings. If they are omitted in one floor it is nearly as bad as if they were omitted in several.

There is a method of calculating the resistance due to the weight of the material in structures, but in most steel buildings it is not a great factor. The thick walls required by the New York building law add much to the lateral strength of buildings here. Any system of metal bracing connecting two columns of a building makes the columns act like the chords of a truss, one in tension and one in compression. When this tension stress becomes so great that it reduces the dead load on the column to zero, the limit of the efficiency of that line of bracing is reached unless the whole is anchored to the earth and the joints in the columns are spliced for tension, all of which is impracticable. In most large buildings there are some points where it is possible to use bracing of some kind. In his practice these places are searched out, and the bracing made as strong as the dead column loads will permit. If all the resistance that seems to be required is secured, it is satisfactory; otherwise, other places are sought where the building may be further strengthened, or, if necessary, some further opportunity is forced. The weight of the building is always taken into account, and its resisting effect actually calculated as nearly as possible. This is a tedious operation, however, which would take some time to explain, and is, moreover, largely a question of judgment. He always tried to be sure that there was lateral strength enough in the steel construction to resist any ordinary wind, and the fewer partitions there are in the building, the more particular he was about it. In many buildings he alternated the columns in double lengths, and relied upon strong connections for stiffness. He called attention to the fact that floors are good conductors of horizontal forces, and also stated that he generally required eight rivets in each end of each beam connecting to columns in such construction.

George A. Just, M. Am. Soc. C. E., observed that it was gratifying that the author had brought this subject before the Society again, as his position in the Department of Buildings of this city afforded a wider field for observation and opportunities for criticism, by virtue of the many plans placed before him daily, than that of any engineer Mr. Just.

Mr. Just. engaged in private practice. He is the first (recognizing the fact that buildings are being erected without accident all around us every day without any *intended* provision against the action of the wind) to attempt to give to each of the elements entering into the construction of the same, although not employed with this end in view, a proper value of resistance to the force of wind to which the structure might be subjected.

He pointed out that the author had taken as a first illustration a building practically the same as the one which collapsed in Monroe Street, New York, during the storm of October 10th, 1894; and had found in the walls and beams alone a resistance value of $7\frac{1}{4}$ lbs., equivalent to a velocity of $42\frac{1}{2}$ miles per hour, and, further, that with beam girders and brick piers of certain size in the fronts, they could take up $12\frac{3}{4}$ lbs. additional pressure, or a total of 20 lbs., equivalent to a velocity of 70 miles per hour, which is about as great as any yet recorded here. It is known that buildings of this type with no special provision to resist wind have been erected and are now standing in this and perhaps other cities, and that the collapse of the Monroe Street building would in all probability not have occurred if the front and the window sashes had been in place at the time of the storm. The fact that the building did collapse is, of course, proof that proper provision had not been made at that stage of the construction when this particular storm prevailed, and he had, of course, no intention to encourage such a system; yet the case afforded a very striking example of either the wind-resisting qualities inherent in this type, built entirely without intention to provide against this force, or that the total resultant effect of the wind, even in high storms, is not as great as ordinarily assumed.

The fact was that the building collapsed from the cumulative effect of conditions all prevailing at that time. The plans had been approved by the Department of Buildings and the materials used in construction were as good as are generally used for this class of structures. However, Monroe Street and other parallel streets in this section of the city, run almost due east and west, hence the front and rear walls had this direction, while the gables ran nearly due north and south. The wind blew from the most unfortunate quarter for a building so located, coming from the northeast, and therefore striking not only the easterly gable at a slant, but entering as well by its open windows and by the front not yet fully erected, thus exerting its pressure over the outside of the easterly and the inside of the westerly gable wall at the same time. The rainfall had been heavy (nearly $1\frac{3}{4}$ ins. in 13 hours), and had soaked the green walls. The wind blew at the rate of 37 miles an hour at three o'clock A. M., about the time of the accident, and reached a maximum of 48 miles, and for a short time 60 miles per hour. The storm can well be called extraordinary for this section, since its

effects were widespread. This storm also caused the collapse of the guide frame of the gas-holder of the East River Gas Company, an open iron-work structure, 198 ft. in diameter and 150 ft. high (the erectors having failed to put in place the diagonal bracing as the work progressed), the chimney of the New York Terra Cotta Company and the walls of a fire engine-house in course of construction, all at Ravenswood. The house of Captain Merritt at Whitestone, L. I., was unroofed. Vessels were torn from their moorings, and much damage was done to shipping all along the coast and Sound, the havoc caused extending as far north as Halifax. A two-story frame house in Brooklyn, N. Y., in process of erection was destroyed, and plate-glass show windows were blown in. At Long Branch, N. J., a portion of the West End Hotel roof was carried away, and summer-houses, greenhouses and barns were demolished. It would also appear that a wind-storm of certain intensity is sometimes not so destructive as a rain-storm combined with a wind of less intensity. The wind-storm of March 28th, 1895, broke the U. S. Signal Service record of 72 miles in New York City, which had stood for 29 years. It blew at the rate of 75 miles per hour for two minutes, and an average of 55 miles per hour during 12 hours. Yet this storm was not nearly so destructive as the mixed storm of October 10th, 1894. The only serious accidents reported were the foundering of a tug in the Upper Bay, the falling of a frame ventilator 5 ft. square and 60 ft. high, from which the surrounding scaffolding had not yet been removed and the collapse of a three-story frame building, just roofed, both in Newark, N. J. In comparing these storms it is necessary, however, to point out that in the rain-storm of October 10th, 1894, the wind was from the northeast, and measured by U. S. Signal Service instruments placed 200 ft. above the ground, while the wind of March 28th, 1895, was from the northwest, and was measured at an altitude of 326 ft. Mr. Just.

He called attention to the fact that in the second or "three-column" example, the author exhibits a structure which, while not actually built, was at least seriously proposed, and gives a resistance value of 4 lbs. to the dead weight, 2 lbs. to poor partitions and a "very open" front, and looks for bracing which shall supply 24 lbs. additional, which, when supplied, induces unit strains in the cast-iron columns incompatible with safety. The author's last example, easily recognized as the so-called "Diamond Exchange" on Maiden Lane, was designed and erected with cast-iron columns. In this case, however, the special details designed for the connections were ignored by the contractor, hence distortion of the frame, which was, however, readily pulled into plumb again, without damage to the brickwork and other parts of the building which were not at the time sufficiently advanced.

It seemed to him that the last two examples only emphasize what has already been pointed out in the earlier discussion of this subject,*

* *Transactions*, Vol. XXVII, p. 221.

Mr. Just. viz., that cast-iron columns should not be used for buildings of narrow base and extreme height, because of the bending induced by necessary bracing, and because the old architectural iron-workers have no sufficient appreciation of the essential details of such constructions and can hardly be made to execute them effectively, even when prescribed.

He thought this whole subject for convenience could be really considered under three distinct heads, viz.:

First.—A more exact determination of the maximum pressure of wind, a better expression for which would be "total resultant effect of wind."

Second.—A determination of the value of the wind-resisting elements in existing buildings, not built with such a view.

Third.—The adoption of more uniform and rational methods in calculation and hence design of modern structures in which the effect of wind is recognized and taken into consideration.

This last, he said, is now receiving more attention from designers of the more recent and better examples of high construction, but the first seems to be as indeterminate as ever. One is first struck by the extreme variations in the records of different observers in the same locality. Thus, for the storm of October 10th, 1894, and for the greatest storm yet recorded in New York City, Dr. Draper, of the Arsenal in Central Park, and Elias Dunn, of the U. S. Signal Service, in the Equitable Building, report the figures in the table on page 209.

These variations are hardly to be explained by the difference in location and elevation of the instruments of the two observers.

In the case of large buildings or on other exposed surfaces of great area, the wind does not act in the manner assumed for the purposes of calculation. The pressure is not uniform, it is seldom normal, and, generally, is not simply progressive in motion, but also rotary.

Of course, if the "total resultant effect" of a wind were well known, an equivalent uniform pressure applied to so-called panel points could still be used, but it would be probably less than that now usually assumed. Hurricanes are excluded from consideration, but the fact that the walls of partially completed buildings do not fall more frequently under the action of ordinary winds is perhaps explained because they are seldom normal to the plane of the wall, and hence less effective than those recorded by machines which receive the pressure normally as well as by the fact that the higher pressures recorded are local and not of the same intensity when spread over larger areas.

He further stated that the relation of pressure to the slope the surfaces of a body present to the direction of wind has recently been determined, perhaps more accurately than ever before, by the experiments of Mr. J. Irminger, of the Danish Society of Engineers, who used velocities of about 16 and 33 miles per hour, and found, for instance, that the

TABLE OF DATA RELATING TO STORM OF OCTOBER 10TH, 1894. Mr. Just.

INQUIRY.	DRAPER.	DUNN.
Velocity of wind, 3 to 4 A.M., October 10th, 1894	19 miles per hour.	37 miles per hour.
Maximum velocity in this storm	20 miles per hour.	48 miles per hour, for five-minute intervals; 60 miles per hour, extreme recorded.
Equivalent pressure per square foot	21½ lbs.	11½ lbs. for 48 miles. 18 " " 60 "
Kind of machine registering velocity	Draper's self-recording.	Robinson anemometer cups.
Kind of machine registering pressure	Draper's self-recording.	By table, calculated from Smeaton's formula— $P = \frac{V^2}{200}$
Height of velocity. Machine above ground	53 ft.	200 ft.
Height of pressure. Machine above ground	53 ft.	200 ft.
Rainfall	1.67 ins.	1.71 ins.
Number of hours in which same was measured	12 hours.	13 hours.
Quarter from which wind blew in this storm	E. N. E.	N. E.
Greatest velocity ever recorded here	41 miles per hour.	72 miles per hour, on a five-minute interval basis.*
Greatest rainfall ever recorded here	8.28 ins., September 23d, 1882.	1.6 ins. in one hour 6.17 " " 24 hours.
Number of hours in which this was measured	19 hours 30 minutes.	One hour and 24 hours as above.

* This record, made in 1876, was exceeded at 11 A.M., March 28th, 1895, when the wind blew from the northwest at the rate of 75 miles per hour for two minutes, measured by the instruments of the U. S. Signal Service in the Manhattan Life Building, 326 ft. above the ground.

pressure on a lozenge-shaped body presenting two of its surfaces at a slope of 30° to the wind (*i. e.*, the two surfaces presented forming an angle of 60° between themselves), terminating at a distance that made the vertical between them "S" units high, was only 25% of that exerted against a plane of equal height placed normal to the wind. He found also that in the former case the total pressure exerted was made up of 18% of pressure on the windward and 82% of suction on the leeward side, while in the latter case pressure and suction were nearly equal, viz., 45% on the windward and 55% on the leeward side. Of course, these experiments are not directly applicable to the case of buildings, since in the experiments the body experimented upon was entirely immersed in the pressure-producing medium, which is not generally the case in large structures.

In conclusion he remarked that Capt. W. H. Bixby, M. Am. Soc. C. E., had also made a comprehensive compilation of the literature on the subject of wind pressure, which was recently published by the Government in a report to the War Department.

Mr. Post. Mr. GEORGE B. POST, remarked that he was not prepared to speak scientifically on the subject of wind pressure in high buildings, although he had read the paper with a great deal of interest. It had been his fortune to put up a great many large structures, but, being very conservative, he had had a fear of various disturbing elements in cage construction, and had preferred to build the cage inside of the walls and anchor the walls to it. In almost every case in large buildings which he had erected, the rear walls of the building opposed to the wind forces were recessed and broken in such a way that the horizontal strain of wind from the exposed fronts would be carried by the floors from the front to the rear walls where it would be safely taken up by the stability of the latter.

He called attention to the Havemeyer Building, 114 ft. long, 175 ft. high, with a westerly front that is entirely exposed to the winds. The building is about 47 ft. wide for 50 or 60 ft. in depth from each end, and at the center of the rear wall there is a round structure for elevators, making a tower of great stability. There are two continuous lines of diagonal cross-bracing at a distance of a little over a quarter of the length of the building from each of the extreme ends, put in for the purpose of taking up any accidental wind strains. The columns stand free on the inside of the walls, and the wind bracing itself was, perhaps, hardly necessary.

He desired to speak of one difficulty which may possibly arise from making a steel frame very rigid by knee bracing. In spite of the greatest care which can be taken in design, it is almost impossible to be absolutely sure in all cases of equal settlement. Unequal settlement has occurred in some cases where the greatest care has been taken, and in such examples unexpected and severe strains might be brought on almost any part of the steel cage, which might have serious results. In case of a rigid steel-cage construction, if the settlement in the wall at the side of an adjacent building should be much greater than on the other side, the tendency would be to throw the whole burden of sustaining the pressure upon the adjoining building, or to make the building itself overhang the adjoining lot. If a building 175 or 200 ft. high, with a steel cage enclosed by a few inches of outside brickwork, should overhang a lot and an order of the court was procured to cut off that overhang, he would like to inquire what would be done with it and how it could be jacked up again ?

In the old system of construction, where the walls are calculated to take care of themselves, with a reasonable amount of bracing from the floors, if one wall settled a little more than the other, the floors got out of level, yet the walls went down straight. He said that he was watching with considerable interest to see what would be the effect of settlement on some of our modern steel-cage construction.

Mr. Post. In reply to Mr. Clarke he stated that his remarks on the occasion spoken of were falsely reported, but he had heard a great deal of it since and, if the report was correct, he said what he did not intend to say.

He thought that the great danger in our present system of construction is from corrosion, unless the greatest possible care is taken during the course of construction to protect the metal from subsequent alternate wetting and drying. He observed that steel-cage construction put up without this proper care is dangerous, and believed that the time would come when there would be failures among these buildings from corrosion of important bearing points. He had had long experience with both cast and wrought iron in connection with masonry; but a very small experience, of course, with steel, as steel is a matter of recent introduction in building construction. The first tier of beams of the New York Times Building, when he altered it, had been in position for at least 35 or 36 years. They were encased, not in plaster or in light arches, but in the heaviest kind of solid brickwork. With the exception of the lower flanges of the beams, they were vertically encased in brickwork; yet many of the beams were discovered to be so entirely destroyed by corrosion that the flange could be broken with the fingers. He also had had much experience in observing the way in which moisture will go through brick walls. He had built a great many tall buildings, and some not so high and with very thick exposed walls. In all storms the moisture penetrated through the northeast walls of the Mills Building, nearly 4 ft. in thickness, and the water ran down on the inside face, although the wall was laid up with hard North River brick with Norton's cement mortar, and was as good a piece of masonry as he had ever seen, and it was not until this outside wall was painted that the water ceased to leak through at the particular face which was exposed to the storm.

He further said that in the remarks which he made at the meeting of the Institute of Architects upon the danger of this form of construction, he had intended rather to enforce his views of the necessity of the most careful protection from corrosion and to state his firm conviction that many buildings had been put up with such recklessness that they would suffer in time from corrosion; not that it was impossible to build steel-cage buildings with safety.

He mentioned that these cases of corrosion were with wrought iron, but he believed the danger would be much less with structural steel. It had been the pride of his profession that its work should endure for ages; the great architectural works of the world have stood for thousands and thousands of years, and he looked with considerable disfavor upon any system of construction which might be relatively short lived. He proposed to build steel-cage construction, and also to use the utmost ingenuity of which he was capable, to protect the iron structure, so far as possible, from the effect of alternate wetting and drying.

Mr. Emery. CHARLES E. EMERY, M. Am. Soc. C. E., called attention to one important difficulty in this class of construction, viz., that of obtaining a proper bearing of the ends of the columns, one upon another. He said that if a construction going on in the city of New York were closely watched it would be seen that if a column did not show plumb, a helper would simply get a piece of plate iron and push it in the joint until the desired result was secured. He had seen this done, not only between the faced joints of cast-iron columns, but between the flanges of very heavy steel plate columns used in the best construction. In one building a large supply of plate iron "shims" of different thicknesses, cut to the shape of one side of the column, was kept on hand, and, when one was inserted, a few slips and a little putty and paint made the whole joint look solid. His observations were made from office windows of adjoining buildings, and show, therefore, that this method of treatment is adopted even for the lower stories of important buildings where the loads are necessarily quite heavy. He had been informed, also, that in some cases the workmen do not take the trouble to get "shims" of plate iron, but use common nails in the joints to make the columns vertical. He concluded that at the best when one side of an important joint like this is cobbled up with "shims" or "Dutchmen," the bearing is really on two lines, and if it be necessary to add a second piece to make a correction in the other direction, the bearing may be on a few points only. He added that such a construction necessarily frustrates all attempts at calculation of unit strains and would seem to make superfluous all refined deductions based on the differences in formulas for columns with square and rounded ends. He realized that there would be difficulty at times in correcting such an evil, but he had successfully accomplished it in the construction of the New York Steam Company's building where the interior loads were carried by heavy cast-iron columns carefully faced and centered by socket joints. He said that though the joint on the base had been leveled up, the top of the first column set did not prove to be level, and the cause was found in the fact that the column had been faced by the contractor in a lathe with two independent revolving heads, instead of in a gun lathe with the column itself revolving. The lathe heads were, however, put in line, and the difficulty finally overcome without the use of "shims."

Mr. Brinckerhoff. H. W. BRINCKERHOFF, M. Am. Soc. C. E., stated that about 1880, when the Brooklyn Bridge was under construction, an anemometer, somewhat similar in design to that mentioned by Mr. Leverich (see page 227), was set up in the center of the river span on the cradle cables. He was then engaged in the drawing room of the bridge, and he thought the design of the anemometer was suggested by George W. McNulty, M. Am. Soc. C. E., and that the instrument was made and set up by A. V. Abbott, Jun. Am. Soc. C. E., both then engaged on the

bridge. It was at first arranged to be self-registering, but as maximum pressures only were looked for, the self-registering device was used but a short time, and after that it was only noted how far the plate was pushed back by the wind. The plate had an area of about 2 sq. ft. He believed it to have been, perhaps, the first anemometer made to measure and record wind pressures directly without regard to velocity. Mr. Brinckerhoff.

Referring to wind bracing, he said that in the new Manhattan Life Building, it does not extend below the top of the adjoining buildings, leaving the structure at that point, apparently dependent upon its neighbors for support. The building to the north of it is a very slight affair and the building to the south is not a very heavy one, and with the large hall on its lower floor would probably not offer much resistance to horizontal stresses.

He stated that the large chimney of the New York Steam Company's boiler house, Station B, was topped out 20 ins. thick solely for stability, and is believed to be safe for a wind pressure of 40 lbs. per square foot.

F. W. Skinner, M. Am. Soc. C. E., remarked in reference to the Manhattan Building, that he had the privilege of seeing nearly all the working drawings and specifications, and that in most respects they are more carefully and more completely designed than is customary in steel buildings. There are two separate sets of wind bracings. The tower has compression members and diagonal members which in appearance are entirely sufficient to take care of all wind pressure on the tower and transmit it to a solid floor in the roof or eighteenth story of the building, which is made of corrugated floor plates filled solid with concrete, to distribute the strains to several vertical panels of what he would call the second system of bracing, which takes the wind pressure down 150 ft. towards the foundations, which are more than 100 ft. lower yet. There are quite a number of panels between columns, he thought as many as six, in which all the columns have knee braces at each floor beam intersection. These knee braces consist of 3 x 3 x ½ in. angle iron in pairs, with three rivets through each end of each angle, and they are placed at connections down to the sixth story. He considered that it is but fair to add that the sixth story is the place where most of the columns change from riveted sections of rolled steel, having a more or less eye-beam shape, to cast-iron columns—the connection of the knee bracing to cast-metal braces in some degree accounts for the omission of the brackets below the riveted work, but of course it does seem strange to see, in all but one panel, the knee bracing stop off in mid air. Mr. Skinner.

There is one point regarding wind pressures, and particularly the contradictory statements and records of conflicting pressures and velocities, which he had never seen brought forward, and he would like to raise the question for the sake of discussion. There is a very consider-

Mr. Skinner. able difference of pressure due to the different densities of air between the limits of a very hot, dry air, and a very cold, saturated atmosphere. His attention had been called in this direction a little more than a year ago when Richmond County was visited by three storms of great intensity, each one said in turn to be the severest storm in many years. In one of these storms the fact was noted that it was a comparatively dry storm, and that very little damage was done to the trees; the following storm was with a wind of similar direction and intensity, but under different conditions of moisture, with the atmosphere near the limit of saturation, and great damage was done to the trees. Before a scientific society of which he was a member, a paper was presented by an engineer who went into the matter in detail and advanced the opinion that different wind pressures result usually from the densities of the atmosphere.

He further stated that it is interesting to note the steps that have been taken in the most recently constructed buildings to provide for wind bracing, and instanced one on Nassau Street where the wind bracing is provided for in many of the columns by solid plate bracket knees braced 2 ft. on the side with two angles on each of the three sides of the web; this building is not particularly exposed, being pretty well surrounded by others, and this is the only provision made for wind bracing. In the Masonic Temple at Chicago, which has been built perhaps four or five years, there are two sets of sway-bracing rods; the vertical diagonal rods of one system extending but one story, making the columns of one story and the two successive floor beams form the struts for each panel of wind truss. The panels of the truss of the other system cover two stories, with the screw-rod diagonals intersecting at the center of the floor.

The American Tract Society Building, now in course of construction in New York, is to be about 240 ft. high, and the only provision to be made for wind bracing, besides the rigidity of connections, consists of lattice girders 4 ft. deep which surround the light well on one of the rear sides of the building at every story above the fourth. The building in plan is something like the letter U.

There is being constructed in Boston a building 10 or 11 stories high which, in his opinion, involves a novel construction. It is wholly a plate-girder construction ; the corner columns are plate girders, and the intermediate ones are of riveted I section reinforced in the lower stories with plates and channels on thin flanges which in some cases have uneven areas to correspond to eccentric loading.

Each one of the four corners has a column, two of which are shown in cross-section (Fig. 1). The webs are from 35 to 51 ins. deep; there are six or eight angles which are reinforced by channels on the outside; these form continuous plate girders from the pavement to the top of the building. In the heavy wall girders in the long side of the

building, there is a further provision not common, in that allowance is made for the temperature expansion and contraction. The girders are web-connected to bracket pieces riveted on the sides of the columns, and have slotted bolt holes at one end; over the portal they are further strengthened by heavy bracket web plates. Mr. Skinner.

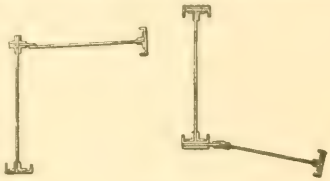

Fig. 1.

Fig. 2 is an end elevation of the building showing to scale in solid black the webs of the wall girders and plate-girder corner columns.

He called attention to the astonishingly poor constructions in New York which sometimes successfully withstand the winds and instanced a building in process of erection on Pine Street a year or two ago which had been built to the eleventh story. It was the poor modern cast-iron construction that is seen here too often, and the brick walls were built up to within two or three stories of the top tier of ironwork then set. After a severe wind, a plumb bob suspended near the top proved to be out of line nearly 2 ins. in a length of 80 ft. To correct this, diagonal transverse struts in vertical planes were put in at several floors and jack screws placed at the heels of the struts set up to right the building; this proving insufficient, wire rope diagonals were fixed in the same planes in the opposite direction, secured at both ends, and an attempt made to increase the tension by straining them by twisting, but this did not succeed. Eventually special connections were made and screw rod diagonals put in with sleeve-nut adjustment, and the framework was brought back apparently into place. Not a single column, however, was brought to a bearing; most of them had to be "shimmed up" $\frac{1}{8}$ to $\frac{1}{16}$ in. One column was adjusted by a small cut nail put in between the horizontal flanges of adjacent sections; when the weight imposed on the column was augmented by the wind pressure, it can be imagined where it would break off.

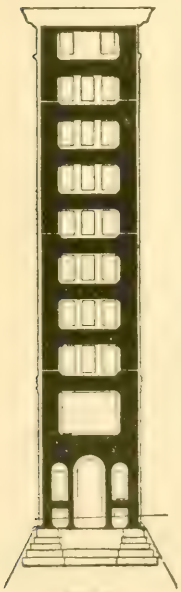

Fig. 2.

He alluded to some of the good constructions which must obtain in Chicago, to produce the result noted by Mr. Stebbins a year ago, when in a violent storm, some 60 or 70 miles an hour, a plumb bob suspended by a line extending over 14 stories of the Old Colony Building, then being erected, only described a vibration of $\frac{1}{2}$ in.; it seemed incredible that there should be so small a vibration, but the measurements were accurate, and the building must be astonishingly rigid.

CORRESPONDENCE.

Mr. Levering.

Mr. W. M. LEVERING remarked that he must disagree with the author in three of the conclusions stated in the paper, and briefly gave his reasons :

First.—The author said in "view of the uncertainty of the cast-iron columns and their imperfect connections for resisting transverse loads, it is but fair to consider them as hinged at each story in determining the stresses for knee braces, bending in columns, etc." And in referring to the strains in continuous steel columns, he stated that the strains on the knee braces would be reduced practically one-half; also, on the same page draws the conclusion that "buildings of this description should be provided with steel columns."

Taking the second example of a skeleton-constructed 17-story fireproof office building 32 ft. front, 100 ft. deep and 194 ft. high above the curb level, located on a corner, he considered the columns without reference to the material of which they are constructed as being continuous in one piece from foundation to top of building, and ascertained what the stresses would be at the different points of connection. It was needless to go into a calculation for the upper stories, since, as stated by the author, the maximum stresses on girders, bracing and connections, and bending in the columns, will occur in the floor system at the level of the adjoining roof and in tiers below it. Assuming that the wind pressure of 24 lbs. per square foot would have to be resisted by structural steel or ironwork and bracing, the horizontal force acting at the level of the fifth floor would be, as stated by the author, 55 500 lbs., which may be divided equally between the three columns in the cross-section of the building at that point.

He observed further, that the details of connection of side columns to girders with knee braces shown in the paper, the distance from the center of the girder to the bottom of knee brace being 2 ft. and the height of the story from center to center of girders being 11 ft., leave a clear, unsupported distance of 9 ft. between the bottom of the brace and the center of the girder of the floor below. If the columns are considered as rigidly connected to the girders, they may be taken as having fixed ends, with the point of contraflexure one-half way between the bottom of the brace and the center of the girder in the floor below, or 4½ ft. from each. The total horizontal force of 18 500 lbs. acting on each column will have to be transmitted from the foot of the knee brace to the point of contraflexure, and from the point of contraflexure to the center of the girder in the floor below, and will produce a bending moment in the column of 18 500 lbs. multiplied by 4½ ft. multiplied by 12 ins., equaling 999 000 in.-lbs. at the point of connection of the knee brace and at the center of the girder.

Mr. Levering.

Assuming the author's data, the dead load on the wall columns at the head of the fourth-story columns will be about 400 000 lbs., which, divided by the 54 sq. ins. in the cross-section of the column will give a uniform compression of 7 400 lbs. per square inch. The strain in the wall columns due to the action of the wind, considering the whole cross-section of the building as a girder standing on end, will be 55 500 lbs., multiplied by 72 ft., divided by 32 ft., which equals 124 000 lbs. direct compression on the leeward and direct tension on the windward column, which, divided by 54 sq. ins., equals 2 300 lbs. per square inch. In addition to this there was a bending moment of 999 000 in.-lbs. divided by 175 ins. resistance, which makes a compressive strain on the one side of the column and a tensile strain on the other side of 5 700 lbs. per square inch. This gives a total compression on the extreme fibers of the interior side of the leeward column at the knee braces of 15 400 lbs. per square inch, and on the exterior of 4 000 lbs. per square inch. In addition to this, assuming the live load (with the author) at an average of 50 lbs. per square foot of floor, a live load of 83 000 lbs. total will be produced, which, divided by 54 sq. ins., equals 1 600 lbs. per square inch, thus giving a maximum compression at the foot of the knee brace of 17 000 lbs. per square inch, and a minimum compression under dead load and wind only of 4 000 lbs. per square inch.

On the windward column there was, as before, a dead load compression of 7 400 lbs. per square inch, and a direct tensile strain of 2 300 lbs. per square inch (the column being considered as the flange of a girder of the full cross-section of the building); also a bending stress, as before, of 5 700 lbs. per square inch compression on the outside of the column at the knee braces, and of the same amount in tension on the inside of the column. This makes a total compression on the extreme outside fibers of 10 800 lbs. per square inch on the outside of the column, and a tensile strain of 600 lbs. per square inch on the inside. Adding the live load of 50 lbs. per square foot of floor, equal to 1 600 lbs. per square inch on the cross-section of the column, gives a maximum compression of 12 400 lbs. per square inch, and a minimum compression of 1 000 lbs. per square inch.

He then stated that the stresses in the foot of the column at the center of the girder of the floor below are the same as at the knee brace, but occur on the opposite sides of the column. The greatest tension in any portion of the exterior columns occurs when the wind and dead load only are acting, and amounts to 600 lbs. per square inch acting on 175 ins. resistance in the column, or, in other words, makes a total bending moment in the column at this point (which may be considered as the joint of the column) of 175 ins. multiplied by 600 lbs. or 105 000 in.-lbs. If the bolts connecting the head and base of the column are considered spaced 15 ins. apart, center to center, this

Mr. Levering.

remaining bending moment will produce a tensile strain on the bolts on one side of the column of 105 000 lbs., divided by 15 ins., equal to 7 000 lbs., which would be safely resisted by two $\frac{7}{8}$-in. bolts connecting the flanges.

Then, taking the middle column at the same floor level, the dead load as stated by the author is 250 000 lbs., and dividing this by 50 sq. ins. area of the column, there results a compression of 5 000 lbs. per square inch. Being in the neutral axis of the building when considered as a vertical girder, this column has no direct strain due to the wind, but has, as before, a bending moment of 999 000 lbs., which, divided by 147 ins. resistance of the column, produces compression on one side and tension on the other of 6 800 lbs. per square inch. The strains due to the wind and dead load are, therefore, a compression of 11 800 lbs. per square inch on one side of the column, and a tension of 1 800 lbs. per square inch on the opposite side. The live load of 165 000 lbs. on the column, divided by 50 sq. ins., gives a uniform compressive stress of 3 300 lbs. per square inch, thus making a total of 15 100 lbs. per square inch on one side of the columns, and 1 500 lbs. per square inch on the other, both in compression. The maximum tension of 1 800 lbs. per square inch, acting on 147 ins. resistance of the column, would make a total moment of 264 600 in.-lbs. tending to strain the bolts connecting the columns. If the bolts are placed 15 ins. apart as before, this will produce a strain on them of 17 600 lbs., which would be resisted by two $1\frac{1}{4}$-in. bolts on each side of the column.

Again, taking the stresses at the head of the second-story columns we find, by similar reasoning, a maximum stress in the leeward column of 19 200 lbs. per square inch, and a minimum stress of 6 000 lbs. per square inch, both in compression. On the windward column we have a maximum stress of 13 200 lbs. per square inch and a minimum stress equal to zero, and on the center column a maximum stress of 16 400 lbs. per square inch in compression, and a maximum tensile stress of 1 100 lbs. per square inch. The maximum tensile stresses are less in this case than at the fifth floor level.

He added that the total bending moment at the foot of the knee brace being 999 000 in.-lbs., a bending moment in the same direction on the foot of the column above of the same amount will make a total bending strain in the bracket of 1 998 000 in.-lbs., which, divided by 24 ins., will give the maximum horizontal stress to be transmitted by wind brace into the girder of 83 250 lbs. In addition to this, the wind brace has to transmit directly from the underside of the girder to the column the amount of direct horizontal stress at the level of the center of girder, amounting to 18 500 lbs., making a total of 101 750 lbs., which is the same as that found by the author for a discontinuous column, and not one-half of it, as stated. The total bending moment which

must be transmitted from the center column to the girder at its head has been assumed to be the same as that of the side column. If brackets are used at this point capable of taking both compression and tension, they will both act at the same time; consequently the strains in each will amount to half of that given for the side brackets. The total stress in each bracket at the center column being one-half of that in the bracket at the wall column, the point of contraflexure of the floor girder will be two-thirds of the span from the wall column, or $10\frac{2}{3}$ ft. Mr. Levering.

The shear in the girder at its point of contraflexure will be 101 750 lbs., multiplied by 2 ft., divided by $10\frac{2}{3}$ ft. or 19 075 lbs., which, multiplied by its leverage of $8\frac{2}{3}$ ft. and by 12 ins., will give 1 984 000 in.-lbs. bending moment at the end of bracket. This is resisted by a pair of 15-in. 180-lb. I beams, which have a resistance of 176 ins. and produces a stress of a little less than 11 300 lbs. per square inch on the extreme fibers of the girder.

The extreme maximum compressive strains in the fourth-story columns amounting to 17 000 lbs. per square inch, and in the second-story columns to 19 200 lbs. per square inch, are excessive in the case given, but it must be borne in mind that they occur only at the points where the columns are connected to the girders, and consequently no reduction for length need be made, and a small addition to their diameter would bring them within the prescribed limits of a factor of safety of six, if it was considered necessary to do so, without very greatly increasing their weight. As a wind exerting a force of 30 lbs. per square foot on any large surface is extremely rare, it is doubtful whether it would be necessary to calculate the column for this extreme case with a greater factor of safety than five. The strain of 11 300 lbs. per square inch on the cross-girder occurs only near the end, where there is little stress produced by a direct loading of the floors, and which diminishes rapidly as the center of the girder is approached, so that the girder being of uniform section, it is unnecessary to use, additional material to provide for this strain in the present case. The principal point in the whole matter is to make the detail connecting the cross-girder and column of sufficient strength to make the joint rigid.

He thought that with good design and workmanship, it was perfectly fair to consider cast-iron columns as continuous, since the dead load, even in the extreme case taken, very nearly overcomes the tensile stresses produced by the bending.

Second.—The stresses in the bracket and floor girders are independent of the continuity of the column.

Third.—It would be unwise to condemn cast-iron columns on the ground of their inability to resist transverse forces due to wind on large buildings, as they have decided advantages in price, in the shorter time required for their manufacture, and also in their ability to

Mr. Levering. resist rust, both on account of their material and the greater thickness of it used.

He added that in thus assuming the defence of cast-iron for columns of buildings he was well aware that he is taking the unpopular side of an argument from the point of view of the engineer, but, nevertheless, it was his opinion that for the special purpose for which its use was advocated it possesses special fitness which cannot be claimed for it in bridges and similar structures, for which engineers have, with good reason, condemned it.

Mr Breithaupt W. H. BREITHAUPT, M. Am. Soc. C. E., wrote that on data determined by observations covering many varied cases, and now generally acted on by engineers in bracing structures against wind, the assumption of a wind pressure of 30 lbs. per square foot of exposed surface is low; such pressure should reasonably be taken at 40 lbs. at least. On the other hand, it is reasonable to count on the resistance of the walls of the building, by carefully determining, as nearly as may be, from the dimensions, openings and material, what this resistance may be. To assume a uniform percentage for this resistance, which varies so much in different buildings, is, at best, a loose method.

The floors of a building are in nearly all cases stiff and continuous enough to more than provide for horizontal bracing; but the vertical partitions, as spoken of in the paper under discussion, are generally insufficient as bracing. As stiffening the structure throughout against vibrations from all causes, the method of vertical bracing by means of knee braces at all connections of beams to columns, in the manner of the old style of wooden framing, has much to recommend it. Such braces should not be under the beams only, but across all four of the angles in the plane of intersection of beam and column. It is generally easily put in, and does not obstruct space; the objection to it is that under unequal loading it induces bending moments in the columns.

Another method of vertical bracing is to have, in effect, vertical webs, not at every panel point, but at alternate panel points, or further apart, as the case may require, extending continuously throughout the height of the building, to the foundations. This bracing, either of rods or stiff, should preferably extend directly across the panels. When this causes detrimental obstruction, heavy gussets are required, and columns and beams must be reinforced for the ensuing bending moments.

A frequent weak point in iron-building construction is that the connections are inadequate. It is hardly necessary here to call attention to the waste of material this means in the way of nullifying the value of heavy sections.

In this connection it is pertinent to say something about the present tendency toward very high buildings. From the standpoint of possi-

bilities of construction there is nothing in the way of heights being still increased. In these structures the principal loads are practically static; the horizontal dimensions are generally such that stability, both of foundation and superstructure, can readily be secured, and the metal is generally so well covered by non-conducting material that temperature effects are not great. But from sanitary, economic and artistic points of view, the maximum appropriate height must be said in many cases to be already considerably passed. An isolated building with large open space on all sides may well be carried to extreme practicable height. But these conditions do not prevail with ordinary city buildings. Streets lined with such high buildings as are now being put up are converted, comparatively, into dark alleys, and the lower stories are, practically, dark, unventilated subcellars. This condition already prevails to a large extent, so that rents for the lower stories have had to be much reduced. A height of 120 to 140 ft., giving, say, 10-story buildings, should be the maximum. To this end there might now well be restrictive legislation. Mr Breithaupt

HENRY B. SEAMAN, M. Am. Soc. C. E., observed that the subject of wind bracing in high buildings has never yet received the consensus of opinion which it deserves. Mr. Seaman.

The practice in bridge construction is now well established at 30 lbs. per square foot of exposed surface with moving train, and at 50 lbs. per square foot for high trestles.

The practice of using 40 lbs. per square foot for buildings is perhaps as well authorized, but the general tendency in structures built without supervision is to lessen this provision and trust to endorsement by reference to similar structures "which still stand."

The reduction of wind pressure (from 50 lbs. per square foot for exposed trestles and high bridges, to 40 lbs. per square foot for buildings) is accounted for by the different character of the exposed surface.

Bridge work is made up of an accumulation of small exposed surfaces, which in calculations amount to but a portion of the area covered by the entire truss. In buildings, however, the entire area is calculated as exposed to the wind, while in fact the actual total pressure is not correspondingly increased.

The proposed practice of apportioning the resistance to wind pressure between the rigid partitions and the comparatively elastic iron or steel bracing, is of questionable wisdom. It is true that the partitions do offer resistance, and so does the iron bracing, but they do not act together. Several years ago a high building in Philadelphia, Pa., was being racked by the action of several engines placed in the upper story. In designing an iron framework to stop these vibrations, a complete system of bracing was put in, with horizontal struts at each floor and diagonal rods between. The system extended the full height of

Mr. Seaman. the building, and the rods were pulled to a strong initial tension. A better opportunity to test the efficiency of wrought iron, as compared with rigid partitions, could not have been desired. The results, however, showed clearly the inefficiency of wrought iron to act with the partitions, which, in spite of all precautions, continued to crack under the vibrations of the engines until the latter were removed.

This, he thought, demonstrates that we must either expect our partitions to take the entire strain, or design the iron work to take it in an emergency, should the partitions be destroyed.

He believed that the author's statement that sway bracing cannot be adopted is perhaps too sweeping. It cannot well be placed in the outside walls on account of the numerous windows, but it is needed there less than on the interior; and bracing can often be arranged in the partitions with no inconvenience to the design of the building. In this connection, it is interesting to note that the entire upper portion of the Chestnut Street half of the Drexel Building of Philadelphia, Pa., designed by Messrs. Wilson Bros. & Co., has not only a system of bracing, but a complete set of trusses, extending up through the partitions, and carrying the building over the Stock Board room and over the bank below. This plan of construction has been successfully adopted in several other buildings since that time.

He called attention to the question of the corrosion of wrought iron, and remarked that it is to be hoped that the design of iron structures will gradually undergo the change which has taken place in plumbing and other sanitary arrangements, where the entire system is exposed to inspection. If the details of the iron work are effectively arranged, exposed and decorated, they will present an attractive finish. Where columns must be embedded in masonry, cast iron is much less subject to corrosion than wrought iron or rolled steel.

He closed by referring to the importance of scientific design, both as to general arrangement and as to details of construction, particularly with regard to secondary strains.

Mr. Leverich. G. Leverich, M. Am. Soc. C. E. stated that the problem in engineering design comprised in the safe construction of the metallic framework of the high buildings lately erected, and conspicuous in this and other cities, when divested of extraneous considerations, is a comparatively simple one. The framework, consisting of lines of vertical columns, connected by and supporting horizontal beams placed in planes one above the other, the latter bearing certain uniform and other variable loads, and the whole to be subject at times as a united system to distributed horizontal forces, is in general a beam, or series of beams joined together laterally, with one end free and the other sustained. It is at once apparent, that such a structure without diagonal members, or their equivalents, which will transmit the stresses due to the resultant applied forces from their points of application

to the foundations, will be unstable; if, however, diagonals may be inserted, a positive solution is easy and need not here be further commented on. Mr. Leverich.

The question to be answered therefore is—what is a sufficient equivalent for the diagonals?

He then pointed out that if the spaces enclosed by the vertical and horizontal members of the framework be closely filled in with the materials comprising the outer and inner walls of the building, such, if sufficiently resistant, will serve as a means to transmit the diagonal stresses; this construction, however, is not permissible in many of the cases submitted to the designer. Generally the outer walls should be detached from the framework, and the inner walls must be placed and provided with openings, without regard to their possible work or efficiency as members of a composite structure.

The other equivalent for diagonals to prevent deformation of the framework is a system of braces connecting the horizontal and vertical members at their several joinings. A slight consideration of this device will show that thereby the beams and columns may be subjected to stresses transverse to their axes; in the former, perhaps, surely opposed by the dead loads they carry, but, in the latter, tending to cause flexure and in uncertain degree thereby to disable these long vertical members from sustaining the dead loads imposed.

Therefore, in conclusion of this treatment of the problem, it may be urged:

First.—That the columns be substantially continuous from foundation to top, and the beams in each direction securely joined to them.

Second.—That diagonals be inserted in as many of the several rectangular enclosed spaces as the case will permit.

Third.—That in all other spaces a brace be placed at each joining, dimensioned to enclose as large a triangle as practicable; also, that where this is done, the connected column be there proportioned to safely withstand the transverse as well as the axial stresses to which it thus may be subjected.

In practice, to solve the problem considered, the measure of the imposed forces must be known. The architect, builders and users of these buildings will fix with reasonable correctness the loads per unit of floor space to be sustained, and with these given, so soon as the design is outlined, the maximum vertical forces to be provided for may be computed with reasonable accuracy. Were these the only forces to be dealt with, a safe plan, consisting of simple vertical and horizontal members, could readily be made without the aid of an engineer. The measure of the horizontal forces, those due to wind pressure alone, and which make necessary the insertion of diagonal parts or their equivalents, is, however, yet indeterminate.

He called attention to the record referred to in the paper read

Mr. Leverich. on wind pressure at different dates at Central Park, in which such ranges from 49¼ to 21¾ lbs. per square foot of vertical exposed area; and, taking these as authoritative, the author prudently says that "not less than 30 lbs. per square foot horizontal pressure on the exposed windward portion of high buildings should be provided for." Presumptively, the pressures quoted were deduced by some accepted formula from the velocities observed at the times mentioned. How fallacious such a procedure is may be learned by reference to a paper entitled, "An Examination Into the Methods of Determining Wind Pressures," * and a preceding paper, entitled, "Wind Pressure upon Bridges," † with discussions thereon. These monographs briefly record the knowledge on this subject up to the date of writing (May, 1881), and but little of real weight, based upon original and pertinent observation, has been added since.

The table of velocities and the consequent pressure of the wind, generally printed in text and table books, commonly known as "Smeaton's," from an early distinguished English civil engineer, are based on limited experiments, concluded 135 years ago, which he did not make, and upon conclusions therefrom, which he did not endorse.‡ It should be called Rouse's table. Other tables, based upon Hutton's and Hagen's deductions (subsequent to Rouse's time), have also been published. These three § are different, and each, for considerable velocities of the wind, is manifestly unreliable. Thus, according to them, one who faces a "strong gale" as he advances has to resist and overcome a force of from 18 to 12¼ lbs. upon each square foot of his exposed vertical section. Ordinary window glass cannot withstand such a pressure, although it commonly does remain intact against such a wind.

He remarked that when the design for the Forth Bridge was in preparation, a series of observations, extending over a period of more than eight years, was made near the site of this structure with the purpose of determining the maximum wind pressures to which the bridge would be subjected.‖ Three anemometers or wind gauges of special construction were employed; one having an exposed surface of rectangular outline 20 ft. long and 15 ft high, or 300 sq. ft. area, and another having an exposed surface of circular outline 1½ sq. ft. in area, were fixed to face always in one and the same direction and toward the west; a third, having also an exposed surface of circular outline of 1½ sq. ft. in area, was pivoted so as to always face the wind current. Each exposed surface was plane and closed; the test plate was hung in a frame, so as to yield under the wind pressure, the consequent movement

* *Transactions*, Am. Soc. C. E., Vol. X, p. 172.

† *Transactions*, Am. Soc. C. E., Vol. X, p. 139.

‡ *Transactions* of the Royal Society, 1759.

§ *Transactions*, Am. Soc. C. E., Vol. X, p. 176.

‖ See *Engineering*, February 28th, 1890, p. 221.

being opposed by springs; the registration was effected by a system of Mr. Leverich
chains, rods and levers, actuated by the moving plate and terminating with an index hand, which oscillated before a graduated scale. The arrangement was crude, and its indications not precise. The observed results from the operation of these three anemometers appear in the following table—the same being a record of maximum pressures per square foot, except the last two columns, which give comparative values of the observations, reduced to a plane normal to the direction of the wind, that for the large gauge being unity.

		Observed.			Computed—Normal to the Wind.			
Dates.	Direction of the wind.	Maximum pressures. Pounds per square foot.					Comparative values—pressure on large gauge being 1.	
		Large fixed gauge.	Small fixed gauge.	Small revolving gauge.	Large fixed gauge.	Small fixed gauge.	Small fixed gauge.	Small revolving gauge.
		a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*
Oct. 27th, 1884.....	S. W.	18	23	29	25.5	32.5	1.28	1.14
Oct. 28th, 1884.....	"	19	29	26	26.9	41	1.53	1.07
March 20th, 1885...	W.	17	25	30	17	25	1.47	1.77
Dec. 4th, 1885.....	"	19	27	25	19	27	1.42	1.32
March 31st, 1886...	S. W.	19	31	26	26.9	43.8	1.63	0.97
Feb. 4th. 1887.....	"	15	41	26	21.2	58	2 73	1.22
Jan 5th. 1888.....	S. E.	7	16	27	9.9	22.6	2.29	2.73
Nov. 17th. 1888.....	W.	27	41	35	27	41	1.52	1.3
Nov. 2d, 1889.....	S. W.	12	34	27	17	48.1	2.83	1.59
Jan. 19th, 1890.....	"	16	28	27	22.6	39.6	1.76	1.19
Jan. 21st, 1890.....	W.	15	38	26	15	38	2.53	1.73
Jan. 25th, 1890.....	S. W. by W.	18	24	27	47	62.7	1.33	0.57

It is to be understood that in this table, columns *a*, *b* and *c* record the pressures as observed; columns *d* and *e*, the mathematical resultants of the fixed gauge pressures upon a plane normal to the wind; and columns *f* and *g*, the comparative values of the pressures recorded in columns *c*, *d* and *e*—those in *d* relating to the large fixed gauge being unity. It will be noticed that column *f* also exhibits the relation between the pressures observed on the fixed gauges, recorded in columns *a* and *b*.

He stated that but little of practical value is to be deduced from this table; it records that the pressures on the small fixed gauge are from 1.28 to 2.83 times those on the large fixed gauge; that the greater pressure on the latter is 27 lbs., from a wind blowing fair on its face, and that the assumption under which the normal pressures written in columns *d* and *e* were computed from the observed pressures

Mr. Leverich. due to wind blowing at an angle to the test planes is invalidated by the discrepant and unreasonable results thus obtained.

In these latitudes, almost invariably when high winds have caused destruction, it has been observed that the glass in the windows, the lighter, vertical walls, and sometimes the roofs, have been first thrust outward, indicating that the moving forces were consequent upon a difference at the time in pressure between the air within and the air without the structure, the latter being much the smaller. This seems to show that the current assumption as to the action of high winds, that they produce a great inward pressure on structures, is erroneous. Engineers and constructors should know the amount of pressure per unit of exposed area of structures produced by high winds as definitely as they know the limits of endurance of the materials they employ in these structures. Doubtless if this had been earlier recognized, before now, conclusive observations would have been made, and exhaustive deductions therefrom, fitting the results for ready application in common practice, would have been published.

Generally the data governing this matter, accepted as authoritative, have been based upon records of velocities of the wind at times of notable disturbance, measured in a manner which did not make quick registry of the effects of extreme waves or pulsations of movement frequently occurring. Two sources of error are consequent; one, the uncertainty of the relation between the observed velocities and the resulting pressures of free currents of an elastic medium; and the other, the difficulty of eliminating from the recording mechanism the disturbing tendency of the inertia of its several parts, acting as it does, to indicate greater or less effects than had been produced at the precise times of observation. The first, as already stated, is one that discredits the several methods of deducing pressures from velocities; the second may be removed by the use of a suitable anemometer, which will measure and record the pressure itself in all its varient phases, and as exerted under the several conditions of effect on the outer surfaces of existing structures. This would include exposure to the wind of plane surfaces, closed and latticed, angular and curved, normal and inclined to the axis of pressure, each of comparatively large area; also observations of the effect upon each surface when it is shielded, and the resulting action of the wind thereon is caused by the partial vacuum developed within the consequent vortex or eddy on the leeward side.

He added that years ago, in the prosecution of an important and conspicuous public work, a large part of which is exposed to all the fitful winds prevailing in this northern latitude, what provision in its design should be made that the structure to be erected might without doubt safely withstand all assaults of the wind was a perplexing as well as an important problem. To aid in solving it, an

instrument was planned to measure and record the pressures of the wind upon exposed surfaces of large area, diverse forms, and generally like those embodied in engineering construction; each under varying conditions, and either normal or inclined to the axis of pressure. Before, however, its details were fully worked out, the work mentioned had progressed well toward completion, and the nascent scheme was consigned to limbo. Mr. Leverich.

From an entry in a note book, under date of January 13th, 1882, he had compiled a brief general description of the anemometer devised. In its design an attempt is made to suspend the plate, having an exposed surface to the wind, so that it may without friction in yielding move but a small space, and that such movement shall induce a pressure upon a column of light fluid, the amount of which shall be measured either by an opposing column of heavy fluid or by other simple mechanism. To a frame of small iron pipes, at one end and normal to its axis is suspended one of the several shapes of test plates, each of thin sheet metal, the surface of which is to be exposed; and at the other end is attached a vane, also of thin sheet metal, of dimensions sufficient to keep the exposed surface always square against the wind, as the whole rotates about a common center of gravity, on a universal pivot, in any plane within 30° of the horizontal. This pivot is on a vertical hollow shaft which revolves with the frame. The test plate is suspended to the frame at four points by strips of sheet metal thin enough to flex somewhat without perceptible resistance, and broad enough to have the requisite strength. Near each of these points, attached to the leeward side of the test plate, is a short piston closely fitted to and slightly entering a short cylinder attached to the frame; each with a thin metal diaphragm connecting the two, and with slight relative movement of these parts acting as a frictionless packing. A small branch pipe from each of these cylinders leads to the vertical shaft, which serves as a main pipe.

The apparatus thus far described is to be erected on a tripod of iron pipes which projects from the roof of the observatory building at a height above erratic or cross currents of air, and from it the vertical shaft is continued down into the building and to a convenient place for observation. To reduce the pressures, and to correspondingly increase the movement of the heavy registering fluid, a transforming device is used. This consists of a small piston fitted into the lower and free end of the hollow shaft or transmitting tube as a cylinder, and a second and much larger piston, fitted to and entering slightly into another and short cylinder closed at the other end; these two pistons and their cylinders having a common axis, and each pair made fluid tight by a thin metal diaphragm, as before mentioned. To the second cylinder is connected a vertical tube of small diameter, reaching upward and open at its free end.

Mr. Leverich.

He omitted a description of sundry details required to provide for an adjustment of the apparatus necessary to insure its correct and uniform operation, also to reduce the friction of its moving parts. Previous to the use of the anemometer, and when there is no wind, the branch and main tubes are to be completely filled with a light transmitting fluid non-congealing at the place of observation, as alcohol, glycerine or the like, and then closed. The larger reducing cylinder and the registering tube is to be filled with a heavy registering fluid, as mercury, up to zero point, on a scale attached to the latter.

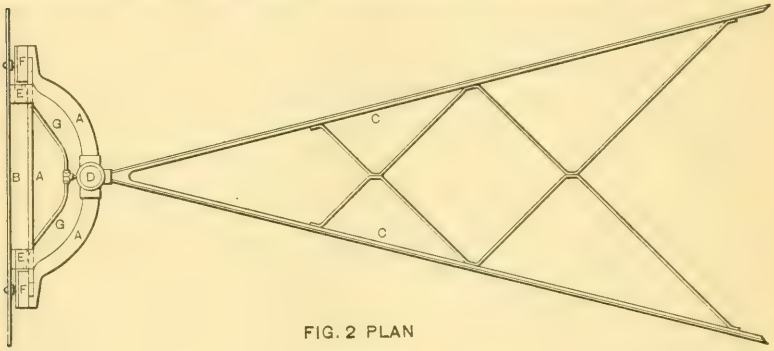

FIG. 2 PLAN

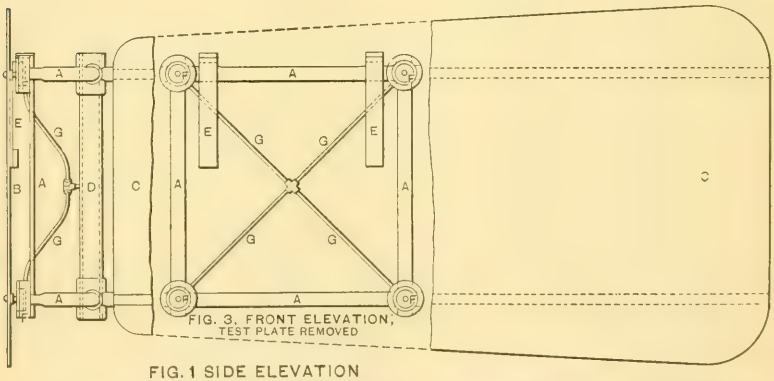

FIG. 3. FRONT ELEVATION, TEST PLATE REMOVED

FIG. 1 SIDE ELEVATION

A simple arrangement of the several parts, designed, however, to revolve in but a single horizontal plane, is shown by the illustrations; Fig. 1 being a side elevation; Fig. 2, a plan, and Fig. 3, a front elevation, the test plate having been removed. In these, *A* is the frame; *B* is the test plate; *C*, the vane; *D*, the hollow revolving shaft and main pipe; *E*, the suspension plates (of which but two are drawn); *F*, the transmitting pistons and cylinders, and *G*, the small branch pipes.

The operation of the apparatus, which he had thus in general described, is as follows: Pressure from a wind current on the exposed test

surface, causing a slight movement of the latter, induces pressure on and a corresponding movement of the transmitting fluid. This pressure at the transformer is opposed by the registering fluid, the movement of which is multiplied, so that its range of vertical oscillations is sufficient to permit close measurements on the scale attached. Instead, however, of this simple method of observation, requiring as it would the constant presence of an attendant, the anemometer was so designed that it should be self-recording, itself registering continuously the compass points and deflections from the horizontal, as well as the varying pressures of the wind currents as they sprung up and fell away. Mechanism comparatively simple, to make the several records, was worked out in the design as first made. Mr. Leverich.

It was proposed that the test plates should have a transverse plane section of 10 sq. ft.; that their pistons should be $2\frac{1}{2}$ ins.; the two transformer pistons $1\frac{1}{10}$ and $3\frac{1}{2}$ ins., and the registering tube, $\frac{1}{4}$ in. each in diameter. Then, under a maximum pressure of the wind on the test plate of 100 lbs. per square foot, it would yield and flex its suspending plates but $\frac{1}{10}$ in., and the mercury would rise in the registry tube 10 ins., or $\frac{1}{7}$ in. per pound of wind pressure indicated.

Guy B. Waite, Assoc. M. Am. Soc. C. E., in closing the discussion, stated that experiences gained in the examination of building construction as submitted to the Department of Buildings of New York City, had led him to present his paper. Mr. Waite.

He had observed that, with few exceptions, the most important new buildings were not receiving systematic consideration for lateral stiffness and stability, and that it was often necessary to criticise such construction for defects of this kind, and to substantiate the objections by actual demonstration.

He had chosen for discussion examples which, in general dimensions, design, sizes of material and manner of location, were similar to plans of proposed buildings which had come under his observation, the only changes made being the insertion of brick mullions in place of a more nearly open front for the first example discussed, and in the substitution of the knee brace and column and girder connections shown in the 17-story building, instead of inferior ones found on the original plans.

As low a wind pressure as could be sanctioned at the present time by any standard authority was taken in discussing these examples, and credit given to every feature of construction which could reasonably be claimed as aiding the protection of the buildings from wind and in enabling them to resist lateral forces. It was considered that by so doing unprofitable issues would be avoided and needed discussions of real conditions would be induced. In the first example (nonfireproof building, 23 ft. front and 85 ft. high), he had desired to call attention to the necessity of some system of stiffening for the front and

Mr. Waite. the rear of such buildings where sufficient rigidity cannot be found in other parts of the construction. The second example (a 17-story building), having knee braces for lateral stiffness, was especially taken for the encouragement of a systematic consideration for the designing of this now common system of bracing high building structures.

He believed that whenever a simple and more direct method than knee bracing can be adopted, it is certainly preferable. That diagonal sway bracing has been used, and can still often be used, is well known. The impression which he had wished to convey when stating verbally that sway bracing could not be used in building construction was simply to call attention to the difficulty of adopting it to the majority of designs. As the part of the engineer in the designing of buildings is to deal with the conditions submitted to him by the architect, he must often be contented with means which otherwise he would not favor.

The manner of depending upon all of the elements composing the structure, such as walls, partitions and the special connections and bracing to act in conjunction in resisting lateral forces, he did not believe to be practicable unless great care is exercised in the construction with that purpose in view.

Their values had, however, been carefully determined for the discussion of this paper, in order to satisfy those who might otherwise use it as a text for dissension from any discussion which could be advanced on wind bracing without considering all of such elements. The calculations for the resistance of walls and partitions were systematically made by the principles of moments; the resisting moment of the dead weight of walls being counterbalanced by the overturning moments of the tabulated wind pressures given in the original paper. The amount of resistance of the brick mullions was determined by assuming the imposed stresses to act in a diagonal direction, and the resistance of the partitions was ascertained by calculating their resisting moments, the resistance acting in a vertical direction. Results of calculations only were given in the original paper.

He remarked that the very interesting discussion of Mr. Levering was instructive in showing the manner of determining the stresses in columns, girders, knee bracing, etc., but that although his determinations of the stresses imposed on continuous columns rigidly fixed at each connection and at floor levels are (with but few exceptions) correct, they seem foreign to any proof that cast-iron columns, as now used in high building structures, should be considered as continuous.

He called attention to the fact that Mr. Levering assumes, for a premise, that the columns are perfectly continuous and rigidly fixed at each floor level, and on that assumption determines certain stresses, from which the conclusion is reached that they may be taken as continuous. The transverse stresses on the columns are about twice as great when taking them simply supported at points of sup-

port as they are when considering them as fixed at these points, and Mr. Waite.
therefore the stresses found will be vastly changed from Mr. Levering's determinations when considering the columns as hinged, as assumed in the original paper.

Mr. Levering finds stresses on columns as follows :

	Pounds per square inch.
Windward columns, maximum compression.....	12 400
" " tension.....	600
Center columns, maximum compression.....	15 100
" " tension.....	1 800

Now, if these columns had been considered as hinged, the corresponding stresses would have been :

	Pounds per square inch.
Windward columns, maximum compression..	12 400 + 5 700 = 18 100
" " tension	600 + 5 700 = 6 300
Center columns, maximum compression.....	15 100 + 6 800 = 21 900
" " tension.....	1 800 + 6 800 = 8 600

It had not been his intention to condemn the use of cast-iron columns in building construction, but simply to assist in the development, from actual data, of the amount of stresses imposed on them under certain conditions, and to show that whenever it is not reasonably certain that the columns will be able to stand under those conditions, it is then but wise to recommend such materials as are best adapted to the case.

He further stated, that in developing for the stresses obtained in the original paper, the assumptions made must be conceded to be all favorable to the construction, thus :

First.—Only the actual exposed area above the adjoining building was taken as acted on by winds.

Second.—It was taken for granted that the adjacent building was capable of resisting the thrust of wind pressure (acting on the structure under consideration) when blowing towards the adjoining building.

Third.—It was assumed that all parts of the walls and columns were perfectly plumb, and that there were no inherent lateral stresses in the members of the structure under consideration.

Fourth.—All parts of the entire structure (dead loads, partitions, connections of columns and girders, and special bracing) were assumed to act in perfect unison in resisting lateral forces—which would be a remarkable circumstance, indeed.

Fifth.—The maximum distributed wind pressure for the highest buildings was taken at 30 lbs. per square foot, which is the lowest given by any known standard authority. The formula used for the

Mr. Waite. reduction of wind pressure from velocity was recently derived from experiments made at Mount Washington, and may be found in Johnson's "Theory of Framed Structures," as follows:

$$P = .004\ v^2 \qquad v = \text{velocity in miles per hour.}$$

This formula gives less pressures for corresponding velocities than most of the older formulas.

It seemed to him that unless all of the circumstances assumed should be favorable the transverse column stresses would be materially increased. In an ideal case it may be assumed that cast-iron columns will act with continuity, but as they are actually constructed such an assumption would be unwarranted, and, in the present case, so much on the side of danger as to be hazardous, for the following reasons:

First.—In the plumbing up of cast-iron columns the main bearing is often brought to one side of the center, giving an eccentric bearing, and when "shims" are introduced to keep the column plumb, they not infrequently either make eccentric bearings or they give a bearing on the neutral axis—which is equivalent to a hinge bearing.

Second.—The casting of the columns is often very uneven; it may have a thin portion at the very point when the maximum stresses are imposed.

Third.—Cast iron is subject to internal strains, which, if sufficiently assisted by imposed stresses (especially those acting transversely) may cause rupture.

Fourth.—Cast iron is subject to defective homogeneity, has very little, if any, elasticity, and almost an absence of ductility. In assuming such columns as non-continuous, it will be acting in the direction of safety.

It has recently been learned that the government of Prussia requires that the safe-carrying capacities of cast-iron columns shall be determined by considering them as having hinged bearings.

He further stated that Mr. Levering's determinations would tend to show that there is no advantage gained by the use of a solid knee brace instead of a simple angle brace, that the stress in the brace and girder is the same whether a solid brace rigidly fixed to the column and girder throughout is used or simple angles fastened to a particular part of the column and girder only. While his calculations for the determination of stresses in columns, girders and brace may not be in serious error, practically considered, his assumption, that the point of contraflexure in the column is at the same place when it is left free to deflect between the foot of the knee brace and the girder connection, as it would be if that part of the column were rigidly fixed in a vertical plane by a solid knee brace, is in violation of the laws governing the theory of flexure.

With the floor girder rigidly fixed (as assumed by Mr. Levering) there will be three points of contraflexure, one near each end of the

girder and one between the points of attachment of the braces (which he takes for discussion); the latter point of contraflexure will not be accurately found by the simple laws of proportion assumed. In determining the stresses in the floor girder Mr. Levering assumes that the entire stress is carried through the stiffening angles of the brace, which is not the case in the solid knee brace assumed in the original paper as more fully discussed hereafter. Mr. Waite.

It is true that the aggregate stresses imposed on the brace and the connections as a whole are about the same, whether it be a solid brace or a simple angle brace. The disposition and distribution of the stresses will, however, be entirely different in the two cases. The solid knee brace rigidly riveted to the steel column (considered in the original paper with the solid knee brace) and to the floor girder taken together with the riveted connection of the floor girder to the steel column, will make the entire adjacent material thus jointed together act as a single piece in taking up stresses imposed on any of its parts. Although the exact manner of the distribution of imposed stresses to individual members cannot be clearly analyzed it may be taken for granted that in all of such braces (some of which are subjected to tension and some to compression) the stress imposed at the level of the floor girder, by the bending in the column below the point of contraflexure, will be taken up and cared for by the column and girder connection and that part of the knee brace adjacent thereto, while the stress imposed by the bending of that part of the column above the point of contraflexure will be mainly carried through the stiffener angles forming the lower part of the solid knee brace. Therefore these angle stiffeners need only be made about one-half as heavy as when they compose the entire brace. No one wishes to go to the extra expense of making solid knee braces unless they have decided advantages over the simple angle iron brace ; and he felt warranted in concluding that not only do they present a more workmanlike class of construction than the simple brace, but the extra material added is not lost, as it takes an active part in performing the functions required of the brace.

He thought that steel skeleton-constructed buildings had not yet passed through the experimental stage, and all doubts as to the efficiency and durability of all parts used in their construction had not been dissipated, and also that the preservation of steel and iron under conditions sometimes favoring corrosion is a subject which should receive immediate and serious consideration, but about which very little is positively known at present.

He believed, with Mr. George A. Just, that much useful data may be derived from a careful study of old existing buildings, and that encouragement should be given to experiments for deriving a positive preventive against deterioration by corrosion of iron and steel in buildings.

Mr. Waite. The query of Mr. George B. Post concerning the effects of unequal settlement in a skeleton-constructed building he thought pertinent and deserving of serious thought. If the foundations of such buildings are carefully planned and constructed there need be little fear of detrimental settlements. If, however, such settlement does occur with a rigid steel frame, the derangement could only be effectively remedied by raising the settled portion and blocking it up in its original condition. The simple righting of a steel skeleton building when the joints are not rigidly fixed is a comparatively simple matter, and can be done by the insertion of diagonals from floor level to floor level and drawing the frame into a true vertical position.

Although most present buildings have withstood prevailing winds, he did not think it followed that the new type of high construction would not be subjected to conditions requiring entirely new and advanced considerations for making them permanently safe; sufficient time to test practically the efficiency of this character of construction has not elapsed. He called attention to the statement often made in the endeavor to show practically that the ordinary assumptions for wind pressure are excessive, that window glass would be ruptured by much less pressures than taken for the buildings, and stated that by actual computation on a $\frac{3}{16}$-in. glass, 36 ins. wide, fixed at its two ends (as well-puttied window glass is held), it is able to sustain pressures in excess of any ever assumed as acting against a building structure.

In conclusion he thought that the remarks of Mr. Just and Mr. Leverich point in the right direction for the determination of such reliable data as can be made of universal assistance in definitely formulating a treatment for the perplexing question of wind bracing for high buildings.

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THE RELATIVE EFFECTS OF FROST AND THE SULPHATE OF SODA EFFLORESCENCE TESTS ON BUILDING STONES.

By LEA MCI. LUQUER, PH.D.

READ FEBRUARY 20TH, 1895.

WITH DISCUSSION.

A series of careful investigations to develop the relation between these two methods of testing building stones cannot fail to be of interest. Both methods have been used for many years for estimating the probable resistance of stone to weathering. The effects of frost have been obtained in various ways, but it is only recently that the establishment of cold storage rooms, where there is plenty of space and where almost any desired temperature can be maintained, has made it possible to carry on these tests conveniently and accurately.

The experiments have been generally only approximate, and the results recorded in a vague way, depending on the appearance of the stone after treatment and the presence of cracks, flaws, or detached particles in the vessel.

R. G. Hatfield* made experiments on the effect of frost on sandstones by exposing specimens in covered vessels, filled with water, from December to April. These specimens were alternately frozen and thawed many times.

Professor J. Henry† states that freezing tests were made 50 times on marble selected for the White House. He also says that tests made by the use of freezing mixtures are very laborious and must be repeated many times before results show.

Braun‡ gives the following method of getting at the probable effect of frost. He "institutes a comparison between the strength of extension of the material and the force of the solidifying water, assuming that a material is not capable of resisting frost when the former is less than the latter."

Bauschinger‡ used a more practical process, "consisting in the exposure of the material 25 times to frost in the open air, the strength before and after the test serving as a guide to the resisting power."

Blümcke,‡ in reviewing the different processes for getting at the probable effect of frost, says they all subject the stone to unnatural conditions and are more or less complicated.

The following method was used by him: Specimens were brought to a very low temperature, by being surrounded by a freezing mixture, were then placed in a vessel, and covered with water and left for three hours. "When taken out the stones were covered with a coating of hoar frost, and if then left for some time in water, a loosening of the small particles was perceptible in the portions not capable of resisting frost." The process was repeated until marked disintegration was noted.

Some tests on sandstone by this method are recorded.

Prof. Wilber‖ tried the effect of subjecting specimens to freezing and then to a temperature of 212° Fahr. in an air bath. The specimens were saturated with water in every case before being put in the vessel surrounded by the freezing mixture. Seven repetitions of this test were made on each sample. His results were as follows: Granites, marbles and limestones were unchanged, sandstones in some cases were slightly affected.

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*Am. Jour. Sci. (II), Vol. XXII, p. 30, 1856.

†Trans. Am. Soc. C. E., Vol. II, p. 148, 1873.

‡Van Nostrand's Eng. Mag., Vol. XXXIV, p. 44, 1886.

‖Tests by Prof. F. A. Wilber, Bull. N. Y. State Museum, Vol. II, No. 10, Sept., 1890, p. 358.

G. P. Merrill* states that the best way to determine the probable effect of frost is to expose specimens of stone, saturated with water, to the actual action of frost, and note the disintegration.

As in many cases, it is almost impossible, or very inconvenient, to get the real action of frost, other methods have been used for producing the desired effect.

The expansion of easily crystallizable salts has been used as a substitute for freezing water, and seems to have been considered at first as about equivalent in action, the salts, in passing from the liquid to the solid state (crystallizing), producing the same rending, shattering or disintegrating effect as water in freezing.

Brard's process, using sulphate of soda (Glauber salt), is the most common of these methods.

M. Vicat,† Ingénieur des Ponts et Chaussées, in 1821 made some experiments with sulphate of soda on mortars and stones. He found that stone which had been exposed to weathering and had resisted the action of frost very well, was noticeably affected by sulphate of soda (saturated hot) after 48 hours. Hence, he claimed that good stones might be rejected if tested in this way. He called attention to the fact that the action was considerably less when, instead of boiling the specimens for half an hour, they were boiled for only 10 minutes.

Prof. J. Henry‡ stated in 1856 that Brard's method was much used, the theory being that a cold saturated solution of sulphate of soda acted on the rock like freezing water, but that recent investigations of Dr. Owen lead us to doubt that its effects are exactly the same as natural freezing, the effect appearing to be chemical as well as mechanical. The experiments were made on porous stone and checked by actual freezing.

C. P. Townsley‖, under the head of external agencies producing weathering of stone, such as frost, says that the artificial test recommended by Brard is the most successful of all other methods. He recommends a cold saturated solution of sodic sulphate, and boiling the specimens for 30 minutes, to get complete saturation. Then suspend specimens and allow them to effloresce in a cool, damp room.

* Building and Ornamental Stones, p. 334, Washington, 1889.

† Annales de Chimie et de Physique, Vol. XXXVIII, p. 170.

‡ Testing Building Material, Am. Jour. Sci. (11), Vol. XXII, p. 30, 1856.

‖ Van Nostrand's Eng. Mag., Vol. XIV, p. 537, 1876.

Soak specimens in solution and let them effloresce again, continuing the tests for a week or more, and the amount of earthy material found in the vessel below will show the action of the sulphate or the corresponding action of the frost. This evidently assumes similarity of action of artificial efflorescence and frost.

The average results on the specimens tested seem to show that marbles and limestones withstood the action of sulphate of soda a little better than granites, and still more so than sandstones.

R. G. Hatfield* states, in relation to the sulphate of soda or artificial freezing, that "the specimens were immersed in a saturated solution for one day and night and the apparent action noted in a scale of from 1 to 12, the larger numbers indicating the greater action of the soda. Other specimens of the same stones were surrounded with small pieces of ice and left for the same length of time. These, when examined, seemed to be affected nearly to the same degree as those submitted to the sulphate of soda test."

C. G. Page† has conducted in this country the most important series of experiments with Brard's process in reference to the selection of material for the Smithsonian Institute Building of Washington. Observations recorded show that sandstone was in most cases much more affected than marble, and that the few specimens of granite tested were acted on in about the same way as the marble. The coarse Pleasantville marble seems to have been more affected than the close-grained varieties. The experiments lasted for four weeks, the specimens being boiled for half an hour and then hung up to effloresce, this process being repeated every day.

Professor J. C. Draper's‡ experiments with sulphate of soda proved that Nova Scotia stone was affected much more than brownstone and very much more than brick. "These results," he states, "also tend to show that frost is not the main agent of the initial disintegration in the climate of New York, since it is not the Nova Scotia stone, but the brown stone which suffers the most severely and rapidly from decay." This inference seems to indicate that Professor Draper regarded the artificial sulphate of soda efflorescence as equivalent to to the action of frost. The tests were carried on for eight days, and the disintegration recorded by loss in weight in parts in 10 000.

* Trans. Am. Soc. C. E., Vol. II, p. 143, 1873.
† Hints on Public Arch., by R. D. Owen, p. 119.
‡ Tenth U. S. Census, Art. on Building Stones, by Hawes & Merrill, p. 384, 1880.

G. P. Merrill* mentions that Brard's process, modified by d'Héricart and de Thury, is thought to act "in a manner somewhat similar to that of water when freezing."† He also states, however, that "this process is not now in general use, as experiment has shown that the salt exercises a chemical as well as mechanical action, and produces results somewhat at variance with that of freezing water."

The objection to Brard's method, or any other artificial method, is that stone, in nature, is not apt to be subjected first to the temperature of boiling water and then to freezing.

In view of the evident difference between the effects of these two methods of testing building stones, this paper has been undertaken to investigate the relation of one method to the other, when carried on under the same conditions and extending over the same periods of time. Theories may be advanced as to whether in the sulphate of soda test there is chemical combined with mechanical action, simply stronger mechanical action, or almost entirely a chemical action. But an investigation into the chemical actions possibly going on is outside the province of this paper, and the resulting facts alone will be given.

The experiments were made on carefully selected building stones. Great care was taken in preparing the specimens, and, unless otherwise stated, they were selected from fresh undecomposed stone. The samples subjected to the two methods of testing were in all cases adjoining pieces of the same stone. The specimens were not sawn out in cubes, as the crushing strength was not afterwards to be determined, but at the same time the rending and shattering effect of hammering was avoided as far as possible. The specimens were prepared with the "rock cutter," used for trimming minerals, and were made approximately of the same size and rectangular in shape.

They were then carefully examined and all sharp edges or loosened particles removed. Finally, they were brushed over with a stiff brush, dried in an air bath at about 120° Cent., and carefully weighed. In order to get the loss very exactly small specimens were used, and the weights taken with great accuracy on a chemical balance. The loss was obtained by the difference in weight before and after the experiments. The usual way in these investigations has been to deal with larger specimens, and get at the loss by weighing the detached particles

* Building and Ornamental Stones, p. 334. Washington, 1889.

† Chateau. Tech. du Bâtiment, Vol. I, p. 262.

very carefully, the exact weights of the larger specimens not being of so much importance in calculating the percentage of loss.

The experiments were commenced with the idea of getting the losses by the latter method; but many difficulties were encountered in obtaining accurate results, and the method was abandoned in favor of getting the losses by reweighing the specimens after treatment and subtracting the latter weights from the former. The 14 duplicate specimens selected for trial covered the different kinds of stones commonly used for building, such as marble, limestone, granite, gneiss, trap, sandstone and brick.

Outline of Method Followed in Making the Sulphate of Soda Efflorescence Test.

The process employed was Brard's method, as modified by d'Héricart and de Thury. *

A saturated cold solution of pure sulphate of soda (Glauber salt) was used, great stress being laid by de Thury on the solution being saturated cold. Experiments made by the French Inspector-General of Quarries have demonstrated the fact that stones which will resist frost and the action of a cold saturated solution of lye are entirely broken up by the action of a hot saturated solution. Experiments made by Dr. Vulté, of the School of Mines, on concentration of soda solutions, developed the following fact: When getting a hot saturated solution of this salt the temperature of the solution will rise above 212° Fahr. (100° Cent.), and will keep going up, until finally it passes what may be called the "critical temperature," when decomposition will take place, SO_2 being driven off and Na_2O being left behind, which may have the solvent action of an alkali on the silicates in the rocks. Decomposition will apparently also take place in the case of the limestones. The normal cold saturated solution of sulphate of soda is of course neutral. Former investigations all demonstrate the necessity of using a cold saturated solution.

The specimens, which had been carefully prepared, brushed, dried and weighed, were boiled in the sulphate of soda for half an hour, in order to get complete saturation. At the end of the half hour, it was noticed in every case that the solution was slightly alkaline, although at the start it had been neutral. In order to prevent any continued chemical action, the beakers were emptied, the specimens rapidly

* Chateau. Tech. du Bâtiment, Vol. I, p. 272.

washed with water, and the beakers immediately refilled with the neutral sulphate solution. After soaking for several hours, the specimens were hung up by threads, and left for 12 hours (during the night) in a dark room.

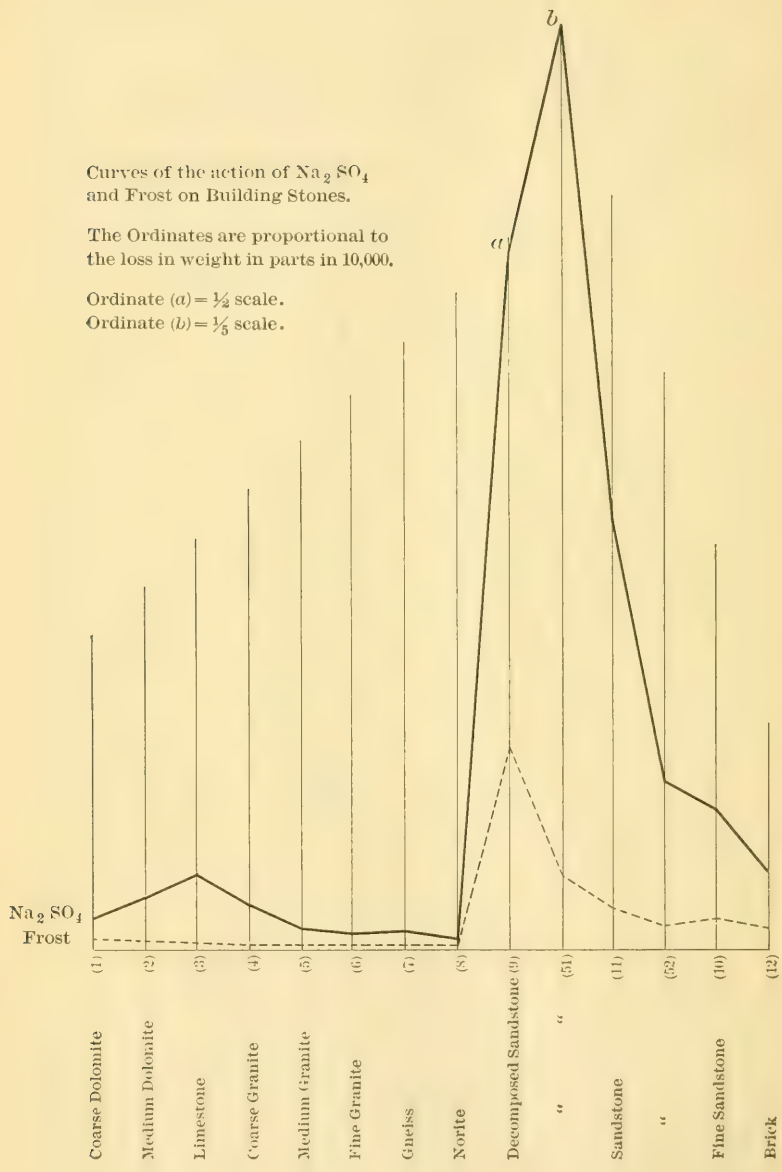
In the morning all the specimens were covered with an efflorescence of the white sulphate of soda crystals; they were then allowed to soak in the solution during the day and again hung up at night. Effloreseing for about 12 hours and soaking for about the same time constituted a period. The experiments lasted for eight periods, and were conducted in this way in order to make them correspond with those made with freezing water, as in the cold storage room the specimens could only be changed night and morning.

In two cases the specimens were allowed to effloresce for 36 instead of 12 hours, to insure thorough action of the salt. The experiments thus really lasted for 10 days. It was deemed that eight periods or days were sufficient, as de Thury states that if a specimen is acted on by this method of testing, the effect will be noticed in five days. The general opinion of others seems to be, also, that a week or eight days is long enough to obtain good results. During the tests the solution was renewed from time to time, and appeared to remain neutral. The temperature of the room varied from 60° to 70° Fahr. (18° to 21° Cent.). Those specimens most affected began to show the disintegrating action of the solution very early in the course of the experiments. At the end of the 10 days the specimens were sprayed with the stream from a wash bottle to remove any adhering particles, washed in water to remove the sulphate of soda, carefully dried in an air bath at about 120° Cent., and weighed again.

The difference between the weights was taken as the loss due to the action of the sulphate of soda. The results are given in tabular form.

Outline of Method Used in Making Freezing Tests.

These tests were made in the same manner as the sulphate of soda tests just described. The specimens were allowed to thaw and soak in water during the day, and were hung up and frozen at night. The experiments lasted the same number of periods, two of which were of 36 hours, to insure thorough freezing. Through the courtesy of Mr. Fellowes Morgan, I was able to use the cold storage room under the piers of the Brooklyn Bridge. The temperature of the cold room was


Curves of the action of Na_2SO_4 and Frost on Building Stones.
The Ordinates are proportional to the loss in weight in parts in 10,000.
Ordinate (a) = ½ scale.
Ordinate (b) = ⅕ scale.
a
b
Na_2SO_4
Frost
(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(51)
(11)
(52)
(10)
(12)
Coarse Dolomite
Medium Dolomite
Limestone
Coarse Granite
Medium Granite
Fine Granite
Gneiss
Norite
Decomposed Sandstone
"
"
Sandstone
"
Fine Sandstone
Brick

from 4° to 10° Fahr. (—19° to —23° Cent.), and the specimens were left to thaw and soak during the day in a room with the temperature at about 85° Fahr. (30° Cent.).

After the completion of the tests the specimens were allowed to soak in water for as long as it took to remove all traces of sulphate of soda in the other series of experiments, after which they were carefully dried and weighed. During the progress of these experiments the deterioration was so slight that the effect was scarcely noticeable, the sandstones only showing the effect by a slight residue in the bottom of the pails in which the experiments were made. The results are given in tabular form.

RESULTS OF EXPERIMENTS WITH SULPHATE OF SODA.

No.	SPECIMENS TESTED.	Original weight in grams.	Loss in weight in grams.	Loss in weight in parts in 10 000.
1..	Coarse crystalline dolomitic marble	71.9020	0.0775	10.78
2..	Medium crystalline dolomitic marble	93.8861	0.1597	17.01
3..	Fine-grained limestone	67.0964	0.1744	25.99
4..	Coarse-grained granite	71.8648	0.1115	15.51
5..	Medium-grained red granite	56.4939	0.0370	6.55
6..	Fine-grained gray granite	43.5910	0.0225	5.16
7..	Rather fine grained gneiss	61.8687	0.0392	6.33
8..	Norite, "Au Sable" granite	35.1173	0.0135	3.84
9..	Decomposed sandstone	39.4294	1.9010	482.12
10..	Very fine-grained sandstone	37.7760	0.1800	47.65
11..	Sandstone	28.0325	0.4070	145.18
12..	Pressed brick	37.4025	0.0930	24.86
51..	Decomposed sandstone	22.9660	3.7235	1 621.31
52..	Sandstone	23.9001	0.1381	57.78

RESULTS OF EXPERIMENTS WITH FROST.

No.	SPECIMENS TESTED.	Original weight in grams.	Loss of weight in grams.	Loss in weight in parts in 10 000.
1..	Coarse crystalline dolomitic marble	63.6407	0.0197	3.10
2..	Medium crystalline dolomitic marble	93.9851	0.0216	2.30
3..	Fine-grained limestone	55.4518	0.0115	2.07
4..	Coarse-grained granite	52.2787	0.0072	1.38
5..	Medium-grained red granite	63.4693	0.0112	1.76
6..	Fine-grained gray granite	58.6149	Very slight, about same as No. 5.	
7..	Rather fine-grained gneiss	52.7260	Very slight, about same as No. 5.	
8..	Norite, "Au Sable" granite	44.4665	Very slight, less than No. 5.	
9..	Decomposed sandstone	38.4055	0.2640	68.74
10..	Very fine-grained sandstone	39.5120	0.0420	10.63
11..	Sandstone	21.9437	0.0312	14.21
12..	Pressed brick	37.1790	0.0255	6.86
51..	Decomposed sandstone	24.1020	0.0610	25.31
52..	Sandstone	20.2285	0.0180	8.89

Attention is called to the following observations, resulting from a study of the curves on page 242. Among the limestones the effect of sulphate of soda seems to have been strongest on the pure limestone (No. 3), while the action of frost seems to have been most marked on the very coarse-grained dolomite (No. 1). The granites seem to have been affected by both methods in the ratio of the extent of the decomposition of the feldspar, and the size of the grains.

The sandstones were all much more affected, by both processes, than either the limestones or granites. The decomposed specimens (Nos. 9 and 51) were very much disintegrated by the sulphate of soda; while the very fine-grained specimen (No. 10) was the least affected by both methods.

The specimen of brick (No. 12) seems to have been more acted on by both methods than either the limestones or granites. Of all the specimens tested the compact Norite ("Au Sable" granite, No. 8) showed the least disintegration.

These results and those of former experiments, although not carried on under the same conditions for accurate comparison, all seem to prove beyond a doubt that the action of sulphate of soda is much more powerful than that of freezing water.

An interesting problem has been suggested by the experiments just completed. Is there any definite relation in time between the effects of frost and sulphate of soda? That is, would the effect of sulphate of soda, for a certain period of time, be equivalent to the effect of frost extending over a definite longer period of time?

Detailed Description of Specimens of Building Stones Tested.

No. 1. Dolomitic marble, very coarse crystalline, from Pleasantville, Westchester County, N. Y. It is called "Snow Flake Marble," and is much harder than the Vermont marbles (Smock). It was perfectly fresh, and was very tough, splitting with difficulty.

No. 2. Dolomitic marble, white medium crystalline, from Tuckahoe, N. Y. According to Smock it seems to be durable, is harder than the Vermont and foreign marbles, and freezing and thawing produce no apparent effect upon it. In preparing the specimens it split quite easily. Little scales of light-colored mica were observed to be present.

No. 3. Limestone, white and fine grained. It is almost pure calcium carbonate, dissolving very rapidly in cold dilute hydrochloric acid, and showing only a trace of magnesium. In preparing the specimens it split very easily.

No. 4. Granite, gray and rather coarse grained, with large feldspar crystals, from Gallager's Quarry, Me. A section showed that the feldspar was chiefly decomposed orthoclase, very little plagioclase being noticed. Biotite, more or less decomposed, was the important mica, and a few little crystals of apatite were observed. During the process of cutting and grinding the section, it was noticed to be softer than the red Jonesborough granite (No. 5). It split rather easily, the feldspar being quite decomposed.

No. 5. Granite, red and medium grained from Jonesborough, Washington County, Me. A section showed the feldspar to consist principally of very much decomposed pink and cream-colored orthoclase. Very little plagioclase was noticed. A little green mica was present, and the quartz contained many pores. In preparing the section, it was noticed to be hard, cutting and grinding with difficulty.

No. 6. Granite, gray and fine grained from Hallowell, Kennebec County, Me. It split quite easily in preparing the specimens, although rather hard. A section showed the very fine-grained character of the rock. The feldspar was very little decomposed. Orthoclase, microcline and plagioclase were noticed. The acicular crystals, mentioned by Smock as occurring in this granite, were observed. Most of the mica was quite fresh, a little green chloritic matter, however, was seen. This granite works easily on account of the small proportion of quartz and the presence of mica.

No. 7. Gneiss, rather fine grained and stratified, from Bedford, N. Y. It split quite easily in preparing the specimens. A section showed the presence of very light-colored mica shreds, giving a stratified appearance to the section. The quartz was in small, rounded grains. Orthoclase, more or less decomposed, a very little plagioclase and microcline, and a few grains of hornblende were present. The rock as a whole, appeared fresh, and there seemed to be a good "bond" between the grains.

No. 8. Norite, called the "Au Sable" granite, from Keeseville, N. Y. It is hard and tough, takes a beautiful polish, and splits with difficulty. According to Smock, it stands high temperature well. A

section showed that it was composed of fresh plagioclase crystals, with a very perfect "bond" and close contact, and pyroxene. In the two sections examined most of the pyroxene was the orthorhombic pyroxene, hypersthene, although the monoclinic pyroxene was also present.

No. 9. Sandstone (brownstone) decomposed, taken from an old building, pulled down June, 1893, in Smith Street, near Schermerhorn Street, Brooklyn.

No. 10. Sandstone (brownstone) fresh, very fine grain, and showing distinct stratification, from Belleville, N. J. According to Smock, the cementing material is chiefly iron and lime, and the stone is unchanged by freezing and thawing. Numerous little scales of white mica were noticed in this sandstone, and it effervesced in hydrochloric acid. A section showed the sandstone to be composed chiefly of very small, sharp fragments of quartz. Little grains of calcite were also noticed.

No. 11. Sandstone (brownstone), fresh, rather more granular in structure than No. 10, and showing no stratification, from Belleville, N. J. According to Smock this stone is not affected by freezing and thawing, and the cementing material is chiefly iron and lime. The sandstone effervesced in hydrochloric acid, and a section showed it to be composed principally of rather large angular fragments of quartz. A few grains of decomposed feldspar and calcite appeared to be present, also.

No. 12. Brick, sample taken from a good specimen of pressed brick.

No. 51 and 52 were pieces of Nos. 9 and 11 that had been soaked in dilute hydrochloric acid for a week.

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DISCUSSION.

L. DeCoppet Berg, M. Am. Soc. C. E., called attention to the small amount of practical information published regarding most important subjects, such, for instance, as the relative corrosion of cast iron, wrought iron and steel, and referred particularly to the almost entire lack of knowledge concerning the weathering qualities of stone. Mr. Berg.

Speaking of another paper recently sent to him by the author, he took exception to a statement contained therein, that coarse-grained stone withstood the action of frost better than fine grained, his experience apparently proving the contrary ; and he took occasion to ask the author whether the experiments under discussion did not prove the reverse, viz., that the finer grained stone is safer in resisting the weather.

As an architect, he stated that it was customary with his profession to select a stone on account of its beautiful color or because it harmonizes with its surroundings, or on account of a desired finish which it will readily take—first, of course, making as sure as possible, by the opinions of experts, that the stone will weather well. When the

Mr. Berg. stones are built in, every precaution is taken to get them of even quality, on their natural bed, etc., and yet after one winter's exposure, frequently, certain stones will begin to show discolorations, and, as year after year goes by, will deteriorate more and more, until, after seven or eight years, they are almost entirely disintegrated, although most of the neighboring stones are perhaps still perfect.

He therefore wished to ask the author if there was any simple practical test, which could be applied at the building, to find out whether two stones of apparently the same quality were actually so.

He added that the only method of preserving stone known in this city is a process with which all are familiar, that of heating the stone to such a degree that it will melt and absorb paraffine applied to the surface to a depth of a quarter of an inch or more, thus filling the pores with a water-resisting surface. The objections to this method are, that it seems to bring out black marks or discolorations in the stone, presumably due to the carbonization of vegetable matter contained in the pores, and that in the course of time the process wears off and has to be renewed, as was done in the case of the obelisk in Central Park.

He concluded by saying that it was still questionable, therefore, whether the repeated heatings of the stone did not deteriorate it more in the long run than the frost would have done had the surface been left untreated.

Mr. Owen. James Owen, M. Am. Soc. C. E., said that he was not particularly well informed on the possibly intricate question of testing stone by either the soda process or by the artificial frost process, but had had considerable experience for a number of years with different varieties of sandstones and more particularly with the sandstones from New Jersey alluded to. Some years ago Professor Egleston enunciated the idea of the optical examination of stones for building purposes and other uses, and in that statement he outlined a definition of a sandstone for building purposes and drew a broad line between the two. He stated that as a rule, in almost all cases, a sandstone with a siliceous binding was a permanent structural material, and that sandstone with an argillaceous binding was liable to deterioration by frost.

He then remarked that in his experience in the use of the New Jersey sandstones he had found out that it was perfectly practicable to select a stone which can be considered absolutely weather proof, and stated that the coarser the stone, the better it was.

The particular element, he continued, in this question of weathering of sandstones brings in their inherent structure. Sandstone might be defined as beginning almost a pure alumina, then the combinations of alumina and silica, and then working up to a pure silica. In the proper line between the alumina and the silica is where the question of judgment enters. In that line also comes the structure of the stone itself. If it is aluminous in its binding, the question of deterioration enters.

The weathering of shale stones when laid on their bed is practically imperceptible, but that same stone, if laid on its wrong bed, will begin to spawl off very markedly in a very short period. The dressing of stone had also an effect; if stone be well rubbed, it is more permanent than one rough faced or with a projecting arras. A coarse-grained silicious-bound sandstone can usually be obtained from any quarry if it is insisted on. He condemned quarries not containing this kind of stone. Mr. Owen.

The peculiar formation of sandstone ridges in New Jersey, he observed, is that one range of hills will have good hard sandstone almost up to the surface of the ground; the next range will consist of what are called there "callous" stone, which is a clay sandstone, so that by experience it is possible to judge on opening a quarry the character of the stone in the one adjacent to it.

He asked if, in the weight test, weight of the particles falling from the stone added to the stone itself gave the same weight as the original specimen? Also, if all the crystals of soda were washed out of the stone?

The question of absolute cohesion of the stone occasionally enters as a factor of permanence. He then cited an instance in which quite a number of the stones from a good quarry checked and the fractures followed no line and no law: they seemed to start off at one point and zigzag across in any direction; there appeared to be insufficient cohesion to stand weathering, although otherwise a good stone.

J. J. R. Croes, M. Am. Soc. C. E., inquired how thin or how thick the transparent sections of stone spoken of by the author in the verbal discussion are; how they are prepared, and the method of examination. Mr. Croes.

CORRESPONDENCE.

E. Gerber, M. Am. Soc. C. E., observed that in 1890, during the construction of the new bridge across the Mississippi at Winona, Minn., the question of suitable stone for the piers arose, and as a limestone was to be found in the immediate vicinity, it was desirable to know its weathering qualities as compared with other stones whose qualities were known. Accordingly he was directed by the Consulting Engineer, George S. Morison, M. Am. Soc. C. E., to make tests by the soda process on stone from Bedford, Ind.; Stone City, Ia.; Mankato and Winona, Minn. The process as conducted by others, he added, was investigated in such records as could be readily obtained, and the method afterwards pursued determined upon as the one which would most nearly approximate the action of freezing and thawing. Mr. Gerber.

Mr. Gerber. He then described the stones from the localities above mentioned, as follows: Bedford stone is an oolitic limestone composed of 97% of pure carbonate of lime; it is of very uniform grain, either gray or bluish in color; has no definite lines of stratification, and is comparatively soft. The Stone City stone, commonly known as Anamosa stone, is a true dolomite, containing 57% carbonate of lime and 41% carbonate of magnesia; it is light buff in color, more or less porous, and shows stratification very plainly. Its grain is not uniform, varying from fine to coarse; it is somewhat softer than the Bedford stone. The Mankato stone, suitable for bridge work, is almost a true dolomite, containing 52% carbonate of lime, 36% carbonate of magnesia and 7% sulphate of lime. It is of a yellowish color, generally fine grained, but has occasional sand holes and is about as hard as Bedford stone. The Winona stone is a magnesian limestone containing 47% of carbonate of lime, 21% carbonate of magnesia, 4% sulphate of lime, and 24% of insoluble matter, mostly silica. It is light buff in color, very fine grained except for the presence of numerous sand holes, and is generally quite hard.

Two samples of each kind of stone, he stated, were taken, making eight in all. The samples were cut approximately to 2-in. cubes, and were then carefully ground to true faces and generally to sharp corners. This treatment was of some value in observing the action of the sulphate of soda on the different parts of the stone. After preparing in the manner above described, the stones were dried in air for about a week and then subjected for about 8 hours to a hot-air bath at 212° Fahr., after which they were all carefully weighed. The samples were then all immersed in water for 24 hours, to determine the relative amount of absorption. After this they were again carefully weighed and then dried for 3 days, the object being to remove as much water as possible before saturating with the sulphate of sodium solution.

A cold saturated solution of sulphate of sodium was then prepared and the stones immersed in this solution and left for 24 hours. At the end of 24 hours the stones were removed from the solution and hung up in the atmosphere at a temperature of about 70° for about 24 hours, to allow the sodium sulphate to crystallize. At the end of the 24 hours the samples were carefully washed with a wash bottle and the washings caught in a beaker, it being at that time proposed to weigh the material detached from the cubes. At the first washing the detached particles of stone were plainly visible in every case; in some, however, the quantity was considerably greater than in others, as the table below indicates. The quantity of detached material from the first washing being very small in some cases, and various other difficulties presenting themselves, the plan of weighing the washings was abandoned and they were not preserved. It was noticed, however,

throughout the experiment, that the washings after each crystallization, in the case of each sample, plainly showed detached material. After the first washing, the samples were again immersed in sodium sulphate, this time for 4 hours, and the drying repeated as before. In this manner the samples were immersed in the solution in all eight times, one time for 24 hours, and seven times for 4 hours each. The periods of drying varied from 20 to 72 hours, according to the condition of the atmosphere. All samples were treated exactly alike; that is, they were all immersed at the same instant and taken out of the baths at the same instant, this being accomplished by having the beakers in which they were immersed standing in a row and the samples all attached to one wooden stick by fine wires. Mr. Gerber.

After the last crystallization the samples were soaked in clean water for a week, the water being frequently changed to wash out the sodium sulphate. After soaking, the samples were dried in ordinary atmosphere for about a week and then subjected to the hot bath the same as before the first weighing, the intention being to have the drying after the experiment as nearly as possible the same as the drying before the first weighing. The table on page 252 gives the results of the experiments.

He added that the faces of the different samples all being ground very smooth, the action of the sulphate of sodium on the different kinds of stone was readily observed. The Bedford stone was acted on very uniformly throughout the entire surface, the resulting faces being something like a sand paper made up of fine pebbles; the corners remained comparatively sharp, and no more violent action was observed on them than on the faces. The Stone City stone was also acted on pretty uniformly, but not as much so as the Bedford, and the corners were broken to a considerable extent. The Mankato stone was affected more in the sand holes than on the smooth portions, and the same was true of the Winona stone; in both cases the harder portions were comparatively smooth after the test, and in the latter case scarcely any action was noticeable on the hard, smooth portions of the faces.

Immediately after the above experiment had been completed, the results obtained being sufficient for the purpose in hand, he had learned, through the efforts of Mr. John Warder, M. E., that he could subject these samples to actual freezing and thawing in a cold storage warehouse. The Union Cold Storage Company courteously consented to have the experiment continued in their warehouse. The samples used above, together with three others, were, therefore, taken to this warehouse, and subjected to alternate freezing and thawing, in the following manner: The stones were immersed during the day in water, and at night hung up in the cold storage rooms, which were at an average temperature of from 0 to 4° Fahr. This part of the work was done by one of the employees of the warehouse, and the process

TABLE OF RESULTS OF SODIUM SULPHATE TESTS.

Sample marked.	From.	Description.	Weight dry. Grams.	Weight after being immersed in water 24 hours. Grams.	Amount of water absorbed. Grams.	Percentage of original weight absorbed.	Weight after sodium crystallizations and drying. Grams.	Amount lost. Grams.	Percentage Loss.
I.....	Bedford	Specimens homogeneous and as nearly alike as may be. Faces true and smooth, corners not very sharp.	311.12	324.02	12.90	4.15	309.98	1.14	00.37
II.....	"		310.38	322.57	12.19	3.93	309.27	1.11	00.36
III.....	Stone City	Fine grained, faces true and smooth, corners sharp. Stratification lines visible, but faint.	278.99	304.81	25.82	9.25	277.20	1.69	00.61
IV.....	"	More porous, faces and corners as above. Stratification lines very plain.	300.51	317.00	16.49	5.45	299.76	.75	00.25
V.....	Mankato	Sand holes in both, faces indented, corners generally sharp. Hard parts smooth.	338.31	350.41	12.10	3.58	337.54	.77	00.23
VI.....	"		330.40	342.23	11.93	3.61	329.77	.63	00.19
VII.....	Winona	Full of sand holes, faces indented, corners battered more or less. Hard parts smooth.	344.73	350.11	5.38	1.56	344.35	.38	00.11
VIII.....	"		343.39	348.37	4.98	1.45	342.95	.44	00.13

was continued for about 10 days or two weeks, no exact record of the number of exposures being kept, when the samples were again dried, as in the previous experiment, and weighed. The results of this test are given in the following table : Mr. Gerber.

Sample marked.	From	Weight before freezing. Grams.	Weight after freezing and drying. Grams.	Loss. Grams.	Loss, per-centage.	Percentage of loss by freezing as compared with soda test.
I.....	Bedford.....	309.98	309.68	.30	00.097	26.3
II.....	"	309.27	308.95	.32	00.103	29.8
III.....	Stone City.....	277.20	276.83	.37	00.134	21.9
IV.....	"	299.76	299.60	.16	00.053	21.3
V.....	Mankato	337.54	337.16	.38	00.113	49.4
VI.....	"	329.77	329.42	.35	00.106	55.5
VII.....	Winona.....	344.35	344.18	.17	00.049	44.7
VIII.....	"	342.95	342.80	.15	00.043	34.1
IX.....	Ashland, brown-stone.....	261.57	261.40	.17	00.068	
X.....	Ashland, brown-stone.....	294.19	293.93	.26	00.088	
XI.....	Hannibal, Mo....	331.56	331.05	.51	00.154	

He then remarked that the time of the one experiment in this case is not the same as the time of the other, and a comparison is, therefore, not as valuable as in the case of the paper under discussion. It is of interest, however, to compare the loss during the actual freezing process with the loss by the sulphate of sodium test, and this comparison is given in the last column of the above table. The relative effect of freezing and the action of sulphate of sodium is evidently not the same for different kinds of stone. Within the narrow limits of the experiments, however, it appears to be reasonably constant for the same kind of stone.

He observed, further, that close-grained stones are less likely to be acted on by frost than coarser ones. The same is true, also, of the author's experiment. Omitting Nos. 5, 6, 7, 8 and 51 in the author's experiments, for obvious reasons, the average loss by freezing is 16.5% of that by the soda test.

In the experiment which had been conducted under his direction this average is 35.4 per cent. When it is considered that the freezing in the latter case was more frequent than the sodium crystallization, being possibly double the number of times these averages approach each other ; and while the experiments described are too few in number and on too great a variety of stones for the small total number of experiments, it is perhaps not unreasonable to expect that a comparatively definite relation in time may yet be determined between the effects of frost and of sulphate of soda. That sulphate of soda is a much more powerful agent than frost in the disintegration of stone he believed to be verified by his experiments.

Mr. Phillips. HIRAM PHILLIPS, Assoc. M. Am. Soc. C. E., wrote that while Director of the Physical Laboratory of the Missouri State University in 1890–92, he had made a large number of tests of building stones and brick with sulphate of soda. The records were burned and the results of the tests are therefore given from memory, but he believed them to be accurate deductions.

All specimens were first prepared by grinding into 2-in. cubes (no chiseling nor hammering being allowed). They were then put in a drier with a temperature of 130° Fahr. and left there 24 hours. The specific gravity was then determined, after which they were soaked in water of 60° Fahr. for 24 hours, to find their absorption. For each series of tests five specimens were prepared and the mean of the five taken as a final result. The parallel faces were made exactly true by a thin coat of plaster of paris, and they were crushed between steel cushions in an Olson testing machine:

1. A set of specimens were crushed after having been placed in a drier 24 hours, and a mean of their results taken as a basis of comparison.

2. A set was subjected to the soda test by being boiled in a solution 30 minutes, and then suspended in a dark room 23 hours; this was repeated 30 times.

3. A set was subjected to the soda test by being boiled in a strong solution 3 hours, and then placed in a dark room 21 hours; this was repeated 30 times.

4. A set was subjected to the soda test by being boiled 6 hours, and then placed in a dark room for 18 hours, which was repeated 30 times.

5. A set was also boiled 12 hours in soda solution, and placed in a dark room 12 hours; this was repeated 30 times.

6. A set was boiled in pure water 12 hours, and placed in drier 12 hours; this was repeated 30 times.

7. A set was subjected to boiling in soda solution 12 hours and then left to stand 12 hours in the solution; this was repeated 30 times.

8. A set was placed in a retort, steamed slightly, the air exhausted, and the soda solution at 100° Fahr. forced into the retort under 20 lbs. pressure and left 30 minutes, and the set finally placed in a dark room 24 hours. This was also repeated 30 times.

The results of these tests led him to draw the following conclusions:

First.—Rocks of low specific gravity and high absorption were almost uniformly affected by boiling in the solution, the effects being more strongly marked the longer the boiling was continued and the stronger the solution used; it was greatest on sandstones and porous brick.

Second.—The results obtained by test No. 7 showed that the specimens were disintegrated almost as fast as in test No. 5, which would

seem to indicate that it was the boiling in the solution that caused the disintegration and not the forming of crystals. Mr. Phillips.

Third.—In test No. 6 the rocks were seldom affected, and when injury occurred it seemed to be in developing cracks and seams which had escaped detection in the preparation of the specimens.

Fourth.—The results from test No. 8 showed less injury than from any other test which would seem to indicate that more injury results from boiling than from the soda crystals.

Fifth.—There was less injury to the specimens in test No. 6 than in test No. 5.

He explained that as the greater number of these specimens were from rock of known durability, the results seemed to indicate that the action of the sulphate of soda is much more severe than actual freezing. A considerable number were entirely disintegrated in tests Nos. 5 and 7, some of them being from sandstone curbing that had stood for 30 years without appreciable decay.

He concluded by pointing out that while some good building stone will not withstand the sulphate of soda test, an engineer would be justified in looking with suspicion on any stone that rapidly disintegrates under the process, especially if accompanied by low specific gravity and high absorptive powers.

F. Collingwood, M. Am. Soc. C. E., remarked that some years ago he tested several samples of sandstones as to their durability. They were much larger than those experimented upon by the author, being about 4-in. cubes. The method pursued was to dry and then weigh them, soak them in water for a day, expose them to a temperature of about 0° Fahr. for a day, and finally dry for another day over the brick work of a steam boiler. This process was repeated for about a month with occasional weighings; but the results were discrepant, and indicated that a longer period of drying was required. The experiments were repeated for another month with two-day periods of drying. The final results were not very satisfactory, however, and seemed to show that a much longer period would be required by this method to obtain positive indications as to the value of a building stone. Mr. Collingwood.

The use of smaller specimens, he continued, is no doubt desirable, provided care be taken that they fairly represent the stone to be tested. It would seem, also, that the method pursued by the author promises to be much more useful than the freezing process.

Lea McI. Luquer, Ph. D., answering Mr. Berg, stated that it is generally accepted as true that, "other things being equal, the value of a stone for building purposes is inversely as its porosity or absorbing power," but that G. P. Merrill, in his report on building and ornamental stones, says that this rule may have exceptions. He called attention to the fact that a coarsely porous stone will not only take up a large proportion of water, but will also part with it readily; and in Mr. Luquer.

Mr. Luquer. case of freezing, the resulting expansion of the water is not altogether expended in pushing apart the component grains of the stone, as would be more the case in a less open stone, a good illustration of what is meant being found in the fact that freezing water will break a narrow-neck bottle while it will not break a wide-neck bottle.

The statement that "water may 'freeze out' of a coarsely porous stone, while in a compact stone it may do much damage," was cited in the introduction to a paper on "The Optical Recognition and Economic Importance of the Common Minerals Found in Building Stones," which he had published some time ago. It was merely used as an example of an extreme case to call attention to the importance of a microscopic examination as revealing the structure, etc., of a stone.

Answering Mr. Berg's second question regarding the practicability of any simple test which could be applied at the building to find out whether two stones of apparently the same quality were actually so, it did not seem to him at all probable that any test satisfying the above conditions could be devised.

All the scientific tests now applied to building stones require skill and time, and, therefore, unless there is some very apparent fault in the stone, the only safeguard for the architect, civil engineer or mason seems to depend on the honesty of the contractor, whose duty it is to furnish approximately uniform material from a quarry, fair samples of the stone having been tested.

Mr. James Owen's statements regarding the durability of the best grades of New Jersey sandstone corroborate the author's tests, as the specimens of Belleville sandstone tested with frost only showed a loss in weight of a little over 10 parts in 10 000.

In answer to Mr. Croes' questions, he would refer to the following works: Atkinson Ganot's *Physics* (for optics); Iddings' translation of Rosenbusch's *Mikroskopische Physiographie der petrographisch-wichtigen Mineralien*, E. S. Dana's *Text-Book of Mineralogy*, and the article on "Building Stones" in the Tenth United States Census (for principles of optical mineralogy and description and use of instruments); Rutley on Rocks, and Methods of Modern Petrography, by Hendsoldt, and L. McI. Luquer, in *School of Mines Quarterly*, Vol. X, p. 212; Vol. XI, p. 29; Vol. XII, p. 132; and Vol. XIII, p. 357 (for the preparation and mounting of sections).

He noted with great interest the results of the valuable experiments conducted by Mr. E. Gerber on the effects of the sulphate of soda and frost on building stones, corroborating, as they do, very closely the results obtained in his own series of experiments, and emphasizing the fact of the undoubted stronger action of the sulphate of soda. The experiments made by Mr. Hiram Phillips also confirm the general results of the author's experiments.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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TRANSACTIONS.

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747.

Vol. XXXIII.—April, 1895.

A LINE OF 28-IN. CAST-IRON SUBMERGED PIPES ACROSS THE WILLAMETTE RIVER, AT PORTLAND, ORE.

By FRANKLIN RIFFLE and ALBERT S. RIFFLE, Ms. Am. Soc. C. E.

READ MARCH 6TH, 1895.

WITH DISCUSSION.

The line of submerged pipes, forming the subject of this paper, is a portion of the main pipe line constructed during 1893 and 1894 to supply the city of Portland with pure water diverted from Bull Run, a mountain stream about 30 miles distant.

With the exception of the submerged section, the portion inside the city limits (about 6 miles), connecting the high-service reservoir on the east side of the Willamette River with the high-service reservoir on the west side, consists of cast-iron pipes 32 ins. in diameter.

Proposals were received for this work three times before the contract was finally awarded. On March 1st, 1893, bids were opened for two lines of 24-in. cast-iron pipes. All bids were rejected, and it was not

until August 15th of the same year that bids were again received; this time for a single line of 28-in. pipes. The specification set forth that bids would be received for both cast-iron pipes and riveted pipes of wrought iron or steel. Each bidder was required to submit with his

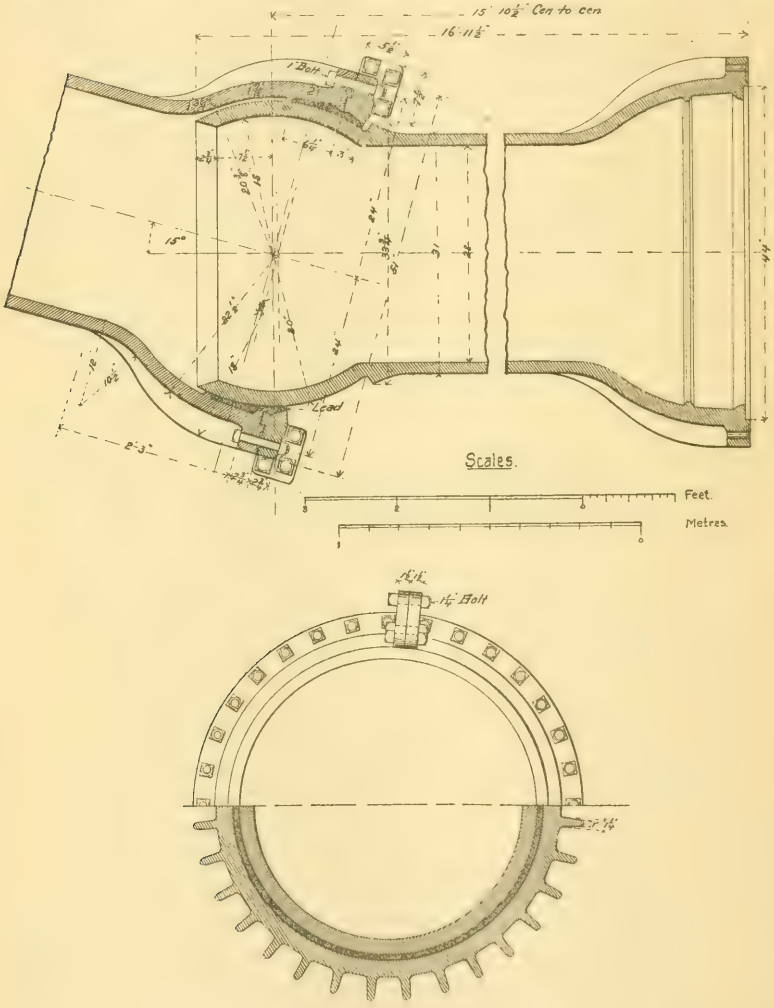


FIG. 1.

proposal a design of a flexible joint. The Oregon Bridge Company (of which the authors are members) was the lowest bidder. This firm's bid was for cast-iron pipes provided with the well-known Ward joint. All

bids were again rejected. About a month later the Oregon Bridge Company was requested by the Chief Engineer of the Water Committee, Isaac W. Smith, M. Am. Soc. C. E., to submit a proposal for cast-iron pipes provided with flexible joints, the design of which had been prepared in his office. This design will be readily recognized as a modification of the Fanning joint (see Fig. 1).

The revised bid of the Oregon Bridge Company was accepted and the contract promptly awarded.

Specifications.—The conditions and requirements of the contract will be best understood from the sections of the specifications appended to this paper (page 269).

Furnishing the Pipes.—Soon after the award of the contract, the contractors requested bids for furnishing the pipes from 16 of the leading pipe foundries in the United States. As the manufacture of these pipes necessitated special preparations and additional appliances, all but three of the foundries declined to bid. Two of these, the Addyston Pipe and Foundry Company, of Cincinnati, and the Ohio Pipe Company, of Columbus, varied but little in the amounts of their bids, and it was exceedingly difficult to decide between them.

The contract was, however, finally awarded to the Ohio Pipe Company, which agreed to manufacture the pipes in lengths of nearly 17 ft., 4 ft. longer than the Addyston Pipe Company would agree to furnish them. The advantages in favor of the long pipes are obvious. One hundred and twenty-six of these pipes would complete the contract, while 166 of the shorter pipes would be required. In the cost of laying there would be a clear saving of 25%, since the cost is largely, if not wholly, governed by the number of joints. In addition to this there would be a saving of about 8 tons of lead, and about 100 tons of freight.

Delivery of the Pipes.—Although it was stipulated in the contract with the manufacturers that the pipe should be delivered at Portland on or before June 1st, owing to delays at the shops and to railroad strikes later on, it was August 20th before the last pipe arrived.

The manufacturers took particular pains in loading the cars to secure the pipes thoroughly, the result being that the entire shipment came across the continent without receiving the slightest injury.

The pipes were unloaded from the cars with a two-way derrick, connected with a stone-cutting yard near the east bank of the river, and

were then rolled down a skidway to the water's edge, whence they could be transferred to the derrick scow as they were needed.

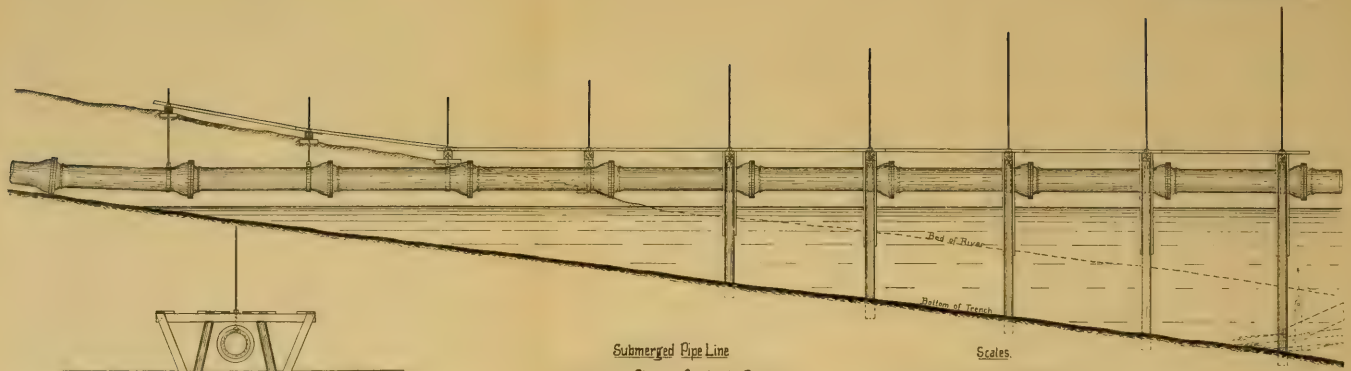
Dredging.—The work of dredging the trench for the pipes began on the east side of the river about August 1st. A stern-wheel steamboat, fitted up with buckets attached to an endless chain operated from one side of the boat, forming a bucket dredge, performed the entire excavation in a perfectly satisfactory manner. As will be seen by referring to the profile (Fig. 3, Plate XXX), the depth of the trench varied from 8 to 23 ft. The width at the bottom was from 10 to 12 ft. With the exception of about 250 ft. on the east side, and about 300 ft. on the west side, the material consisted for the most part of fine gravel and coarse sand. On the east side the bed of the river consisted of boulders and hard pan firmly cemented together. The excavation of this portion of the trench progressed so slowly that nearly a month was consumed before it was completed. On the west side soft mud (deposited from a sewer which discharged into the river immediately above the pipe line) was encountered, making it necessary to dredge to a depth of 23 ft., to secure a solid bed for the pipes. Here, also, slow progress was made, owing to the inflow of mud from the sides of the trench. Even after firm material was reached, the trench became partially filled with mud before the pipes could be laid; but they readily sank through the soft mud to a solid bearing.

Occasionally trees, logs and snags were found buried beneath the bed of the river, which added somewhat to the difficulties of the work, but they were promptly disposed of by the use of powder and a snag-boat whenever they interfered with the dredging. The hull of a vessel completely buried in the sand was torn into fragments by powder before it could be removed.

The dredge was kept on the line by means of a row of piles driven about 35 ft. apart (except in the channel) above the pipe line at a convenient distance from the trench. These piles were afterwards used for keeping the pipe-laying barges on line.

About 18 500 cu. yds. of material were excavated with the dredge—an average of about 10 cu. yds. per linear foot.

Rejected Pipes.—During the month of August all preliminary arrangements were completed for beginning the work of pipe laying. The cradle (Plate XXXI) which had been framed on the pipe-laying barges, was in position ready for duty; a number of pipes had been delivered



Submerged Pipe Line
across Willamette River at Portland, Oregon.
Method of Laying in Shoal Water near Shore.

FIG 2.

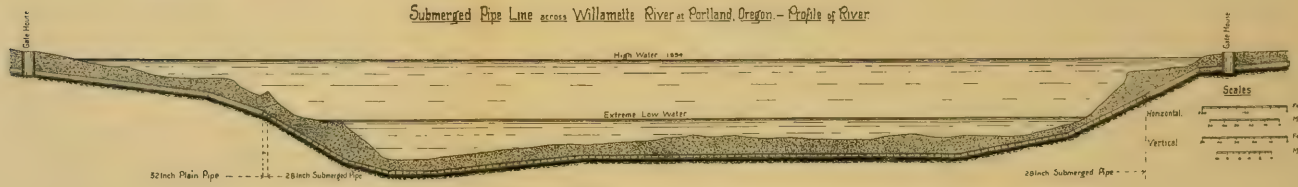


FIG. 3.

on board the barges and tested in the testing machine, and the contractors were ready to begin laying pipe on September 1st, when a letter was received from the Chief Engineer stating that the local inspector had reported that the ball ends of the pipes had not been finished to a truly spherical surface, and that he would require the defects to be remedied before he would permit the pipes to be laid. This discovery of alleged defects in the pipes, after they had passed the inspection of the shop inspector, placed the contractors in an embarrassing position. To turn the ball ends of the pipes again would require the construction of a special lathe, during which time the work of pipe-laying would be postponed indefinitely, probably until it would not only be hazardous but foolhardy to begin the work, owing to the sudden and frequent rises in the river during the winter or rainy season. In other words, to remedy the defects as required by the Chief Engineer, meant a delay of one year, and the contractors were under heavy bonds to complete the work by November 1st, 1894, the forfeiture for non-completion of the contract within the time specified being $200 for each day's delay.

Before taking further action in the matter, the Chief Engineer consented to permit the contractors to lay several pipes in the trench on the east bank on condition that the joints be tested to his satisfaction. A connection was made with the 32-in. main at once. As fast as each pipe was laid and the joint calked, the end of the pipe was raised high enough to revolve the ball end 15° in its socket, and was then lowered to a bearing in the trench. After eight pipes had been laid in this manner a cast-iron cap was bolted to the end of the last pipe, and a pressure gauge was attached. Water was then admitted through the gate on the 32-in. pipe line, the water having been supplied by the East Portland Water Works for this experiment. At 10 lbs. pressure every joint leaked considerably. The contractors desired that the pressure be increased, but the Chief Engineer believed that the defects could be best demonstrated to exist by using a light pressure. The experiment, however, was continued with an increase of pressure. It was soon apparent that the leakage diminished as the pressure increased, until at 45 lbs. pressure it ceased entirely, the eight leaky joints having become absolutely tight.

The contractors were now convinced that they could make the joints of the entire submerged pipe line practically tight as the work pro-

gressed, whether the ball ends were defective or not. But after having laid three more pipes a peremptory order from the Chief Engineer was received to suspend operations until action could be taken by the Water Committee. The Water Committee did not meet to consider the matter until a week later. In the meantime the Chief Engineer formally notified the contractors that his chief inspector had carefully examined the 16 pipes lying on the pipe-laying barges, and, acting on his inspector's report, he had rejected 13 of the pipes as not fulfilling the requirements of the specifications.

At the meeting of the Water Committee, the Chief Engineer took the position that the ball ends of the pipes were not truly spherical, and advised that they should not be accepted until they were made to comply with the specifications. The contractors argued that the lathe work had been performed under the personal supervision of a competent inspector appointed by the Chief Engineer; that the pipes having been once inspected and accepted through a duly authorized agent, it was unfair to refuse to accept them because a second inspector found fault with the workmanship nearly three months after they had left the shops, and six weeks after they had reached their destination; that in the absence of specifications for the lathe work the only test to be applied was that of adaptability to the requirements of the contract ; that the workmanship on the ball ends was of such a character as to permit them to move in their sockets with the greatest ease while the pipes were being lowered into position, and that whether the joints leaked or not was immaterial so long as they were made tight after the pipes were in the bottom of the trench; and that the test imposed by the Chief Engineer was contrary to the specifications, the final test being the only one prescribed.

The Chief Engineer refused to believe that the joints could be "pulled" tight by hydraulic pressure, except under the most favorable conditions, and argued that such conditions would not prevail in the bottom of a trench excavated in the bed of the Willamette River.

The Water Committee decided to permit the pipes to be laid, and to make the payments as stipulated in the contract, the contractors to be held responsible for all rejected pipes. As, under the terms of the contract, the contractors were held responsible for all the pipes laid, whether perfect or defective, they promptly accepted these terms.

While some of the members of the Committee undoubtedly believed

the undertaking would prove a success, there is no doubt that the Committee was largely influenced by the fact that the re-turning of the ball ends of the pipes would postpone the completion of the new water system another year, during which time the city would be paying interest on bonds to the amount of more than $2 000 000 without receiving the slightest benefit in return for this outlay.

It is to be regretted that the three accepted pipes were not subjected to the same test as the first eight pipes laid, for the authors confidently believe that they also would have leaked under like conditions. While it is altogether probable that radial inequalities of $\frac{1}{1000}$ or even $\frac{1}{10000}$ in. in the ball end of a flexible joint may be the cause of more or less leakage, on the other hand it is extremely doubtful if the most accurate lathe work attainable would insure an absolutely tight joint under the conditions of the imposed test. During the experiments it was observed that the leakage was in every case confined almost entirely to the upper portion of the joint, the extreme lower portion being tight. This naturally suggested a secondary cause of leakage, which the most accurate workmanship would not overcome, viz., the extreme weight of the pipe. Each pipe weighs very nearly 5 tons. As the pipes lay in the trench, their weights were so distributed that a comparatively small portion of the entire weight was borne by the sockets. But in lifting the ends of the pipes 4 ft., the test imposed, the additional weights thrown on the sockets had the effect of slightly compressing the lead beneath, which, of course, produced more or less leakage in the upper portion of each joint.

It may be interesting in this connection to know the extent of the defects which caused the rejection of 13 out of 16 pipes. The inspector on the pipe-laying barges was instructed to test the surface of the ball end of each pipe, and to keep a record of the radial variations. Although the methods employed were more or less crude, it is believed that the work was done conscientiously, and that the results are sufficiently accurate for the purpose. The examples given below have been kindly furnished by the inspector. The variations were measured with a micrometer on the line of the axis of the pipe, and are expressed in thousandths of an inch. Column 1 contains the shop numbers marked on the pipes. Columns 2 and 3 contain the amounts of radial variation near the edges of the ball at equal distances from the center. These variations are maximum in each case.

and the 12 numbers selected present a fair average for the entire lot of pipes.

Number of Pipe.	Variations from radius at center, measured near each edge.		Number of Pipe.	Variations from radius at center, measured near each edge.	
25	−0.005	−0.012	84	+0.009	+0.009
35	+0.010	+0.010	95	0.000	−0.012
45	0.000	−0.007	106	−0.013	0.000
55	0.000	−0.012	115	−0.011	0.000
65	0.000	−0.013	125	0.000	0.000
75	+0.012	+0 012	130	0.000	0.000

An inspection of these data shows a lack of uniformity in the nature, as well as in the extent, of the inequalities on the surfaces of the balls. Nos. 35, 75 and 84 were evidently flattened at their centers. This flat zone was found in most cases to be 1½ or 2 ins. in width. This feature was reversed in No. 25, there being a projection on the central zone about 2½ ins. in width. Nos. 125 and 130 were pronounced perfect. The remaining cases cited above were apparently perfect on one-half of their surfaces only.

Local machinists and mechanical engineers who were consulted by the Chief Engineer almost with one accord regarded these radial variations as evidences of exceedingly poor workmanship. The chief inspector in his written report to the Chief Engineer expressed the opinion that the inequalities on the surfaces of the balls would render the joints inflexible, that there could be no "articulation," as he expressed it.

It is to be hoped that this phase of the subject will be thoroughly discussed by those members who have had experience with ball and socket-joint pipes.

Description of Pipe-Laying Device.—The apparatus used for depositing the pipes in the trench was designed by the authors. The method of using this device is clearly shown in the accompanying plates.

For laying in shallow water near each bank trestle bents were erected, one for each pipe, from which the pipes were suspended by long screws 1¼ ins. in diameter, by means of which they were gradually lowered into position (see Fig. 2, Plate XXX).

For laying in deep water a cradle (see Plate XXXI), constructed in the form of an inverted bowstring, was employed. One end was supported and pivoted between two barges, placed 10 ft. apart, while

PLATE XXXI.
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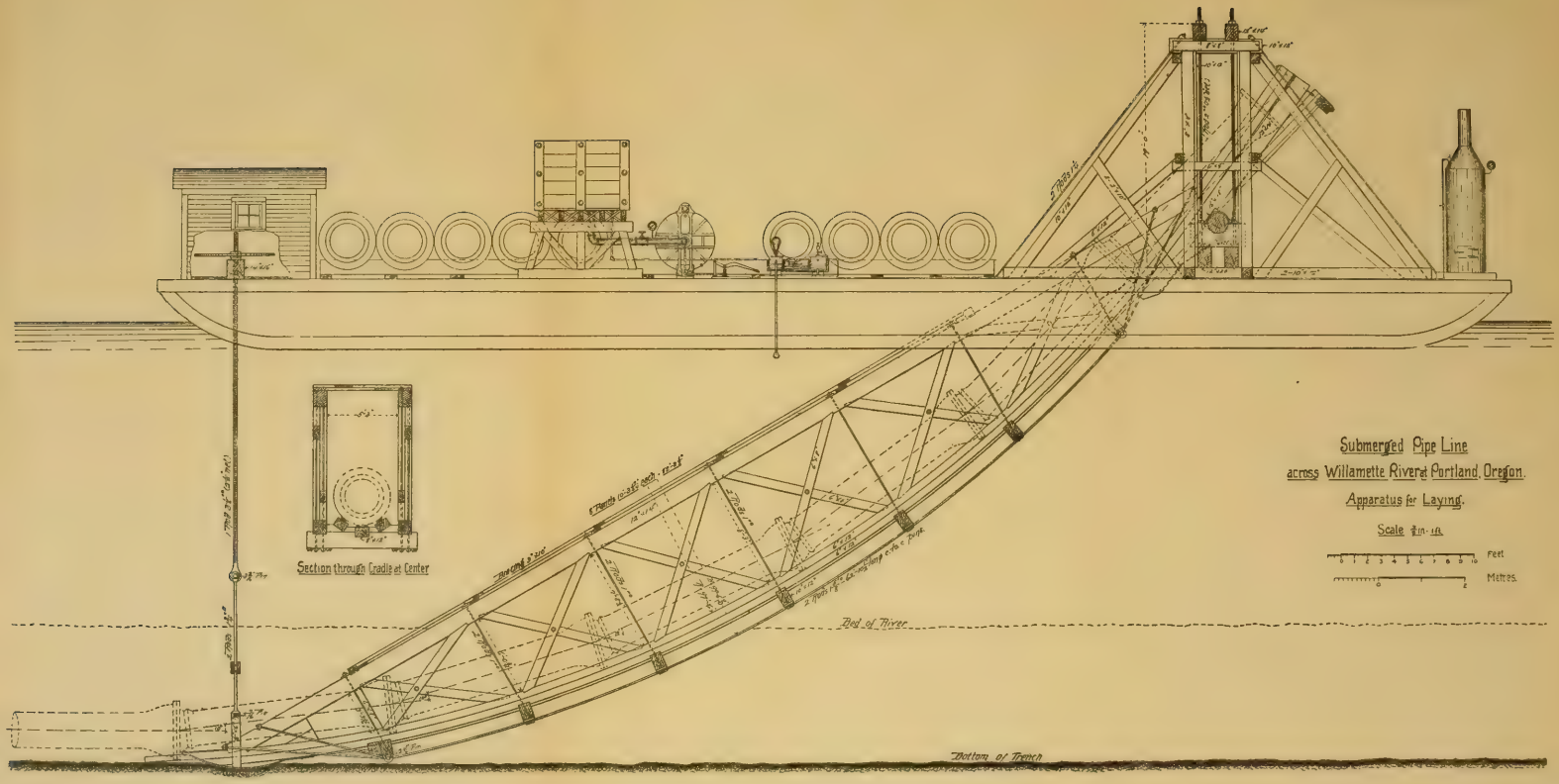

Submerged Pipe Line
across Willamette River at Portland, Oregon.
Apparatus for Laying.
Scale 1 in. = 10.
Feet
Metres.

the other end was suspended between the barges at the rear by a long rod, which was always so adjusted as to permit the cradle merely to touch the bottom of the trench.

The stresses in the cradle were carefully calculated, a factor of safety of 10 having been used in determining the dimensions of the various members. This may appear absurdly large at first thought, but after noting the severe treatment the cradle received during its progress across the river, not only from the imposed load, but from such extraneous influences as heavy swells from wind and passing steamboats, the authors are convinced that the factor used was none too large for the requirements.

All wooden members in the cradle consisted of full-length timbers, those forming the bottom chord being 100 ft. long. An auxiliary bottom chord, consisting of two 1¼-in. round rods, was added as a precaution against a possible weakening of the timbers, caused by bending them to the required radius.

The beam supporting the forward end of the cradle rested upon trunnions held in place by four 8 x 12-in. vertical posts, which served as guides. These posts were securely braced in three directions, and were capped by 12 x 14-in. timbers, through which two rods, each 2 ins. in diameter, passed to the trunnions below. This arrangement answered the purpose of a lift for the forward end of the cradle. The height of the frame was sufficient for a maximum elevation of 17 ft. This device made it possible to maintain a uniform angle of inclination for all depths of water.

Two 12 x 20-in. beams were laid side by side under the trunnions, the ends being supported on the centers of the barges. Whatever the position of the trunnions, blocking was inserted between them, while the rods were kept sufficiently slack to throw the weight directly on the beams.

The hanger from which the rear end of the cradle was suspended consisted of a 3½-in. round rod, with threads cut its entire length, hung from a 14 x 16-in. beam laid crosswise of the barges. The lower end of this rod was connected with a curved stirrup attached to the cradle.

The slide, on which the pipes were connected, and down which they moved into the trench, was composed of three 8 x 12-in. timbers laid flat on 10 x 14-in. floor beams. The timbers were shod with flat

rails, spiked every 2 ft. with countersunk rag spikes. Two lines of rails were laid on the center stringer and one on each outside stringer. The rails were used for the double purpose of reducing friction between contact surfaces, so that the pipes would slide easily, and of preventing excessive wear on the timbers. The slide was made to conform in cross-section to the outer circumference of the pipe joints.

To provide a continuous slide to the bottom of the trench an apron was attached to the cradle, being hinged at the first panel. The apron was shod with heavy plate iron. It answered the purpose admirably, even on the east side where there were many boulders.

Pipe Laying.—Pipe laying began on the east bank September 21st. The first 12 pipes were connected and suspended from the trestle bents previously referred to, just above the water-line. Five pipes were connected and suspended from cross-timbers on the pipe-laying barges directly over the center line of the cradle, which was suspended only a few feet below the water-line. The barges were then moved into position at the end of the trestle, and the two sections were connected. This formed a continuous line of 17 pipes suspended over the water. The pipes were then gradually lowered by means of wrenches until the last five rested on the cradle, when the top lateral bracing was put in place. As soon as this was accomplished, the pipes suspended from the trestle bents were lowered simultaneously with the cradle to the bottom of the trench.

Laying from the cradle then began, and the work was prosecuted vigorously until shoal water was reached on the west bank. The pipes on the cradle were then suspended by long screws from timbers laid across the barges, the cradle was pulled out of the way, bents were erected, and the pipes were suspended and lowered as on the east side.

The weight of the pipes on the cradle tended to push the pipe-laying barges ahead. Four 2-in. stern lines fastened to pipes already laid, and extending to snubbing-posts on the barges were used to prevent any forward movement while the joints were being made. When ready to move ahead, men stationed at the snubbing-posts slowly and steadily slackened the lines, until the cradle moved the required distance. The lines were then made fast, and two more pipes were connected.

At times, owing to an ebbing tide or an abrupt change of grade in

PLATE XXXII.
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the bottom of the trench, the end of the cradle would sink into the sand and gravel sufficiently to arrest the movement of the barges, even though the lines were slack. This difficulty was overcome by a few turns of the wheel wrench which operated the rear suspension rod.

The barges were kept on the line by means of a float or raft made of piles attached to the up-stream barge and fitted between it and the row of piles described under the head of dredging.

While laying pipe with the cradle 16 men were employed as follows: Foreman, 1; engineers, 2; testing the pipes and cleaning the ball ends, 6; melting lead, 1; pouring lead, calking and bolting, 6. Two members of the contracting firm were present most of the time the work was in progress. An expert diver was also employed continuously. With the exception of the diver, Mr. Ivar Johnson, of Chicago, none of the men had ever been employed on similar work. It required some time, therefore, to train them thoroughly before the work progressed smoothly. Two weeks of almost continuous rain also impeded the progress to some extent. Nevertheless, 100 pipes were laid in 20 days, an average of about 80 lin. ft. per day. This required 10 lead pourings and calkings for 40-in. joints, and the bolting of five sleeves, each containing 38 bolts, to the flanged sockets of the pipes. Toward the close of the work, during exceptionally fine weather, from six to eight pipes were laid per day of 10 hours.

The line of pipes was tested by hydraulic pressure about every 200 ft. laid. When ready to test, the cast-iron cap, referred to elsewhere, was bolted to the flange of the last pipe on the cradle. Water was admitted through the gate on the east bank. Pressure was then applied by a double-acting steam pump, located on one of the barges. The pressure was continued until the derrick scow returned with a new load of pipes—usually the greater part of one day. During these tests the diver carefully inspected each joint and the pipes in general as they lay in the bottom of the trench. Leaks were easily located and were promptly calked. But little calking under water was necessary, however, the line being practically tight from first to last.

In making frequent tests the contractors had two objects in view: first, the final tightening or calking of the joints as they lay in position by pulling the ball ends tightly into the lead; second, the detection and stoppage of any serious leaks before the pipes became covered with sediment. That the "pulling" process was a success is fully

proved by the following instance: When about 650 ft. of the pipe line had been laid, a pressure of nearly 250 lbs. per square inch was applied for a few minutes; this had the effect of pulling the joint at the reducer, which connected the 32-in. line with the submerged line, an additional $\frac{1}{4}$ in. This joint had been started by previous tests, but in this instance the increased pressure gave the joint an extra pull, although the power was applied 650 ft. distant. The weight of the pipes laid when this test was made approximated 200 tons.

During the several tests it was impossible to determine the condition of the line with any degree of accuracy on account of the leaky condition of the gate. It was considered a good indication, however, that at the last test the pressure gauge stood fully as well as at the first test, when every joint was visible and showed no sign of leakage. For this reason it is believed that the ball and socket joints are practically tight.

The line was subjected to 13 tests, including the final test prescribed in the specifications. This test was made after the line was connected with the 32-in. main on the west side, and consisted of a continuous pressure of 200 lbs. per square inch for a period of 24 hours. According to the report of the engineer who conducted the test, the leakage was about $\frac{3}{4}$ gall. per minute. Although an attempt was made to determine the amount of leakage in the two gate chambers and at the pump connections, no accurate results were obtained. It cannot be assumed, therefore, that the submerged pipe line is responsible for any considerable portion of the reported leakage. The test also included 600 ft. of 32-in. pipe covered to a depth of from 10 to 15 ft.

Broken Pipes.—During the 11th and 12th tests a pipe was broken each time. In each case the break was doubtless caused by the wedging of the ball in its socket, the end pressure concentrating an enormous strain on a comparatively small portion of the socket. The first break occurred in the socket of the second joint from the end, while the second break occurred in the socket of the third joint from the end. In each instance the fracture extended spirally around the pipe for half its length. Four days were consumed in replacing each of the broken pipes. In the first case, it was necessary to drive piles, and to raise several pipes already laid by means of long screws, in order to get the broken pipe above the surface of the water. The first pipe

PLATE XXXIII.
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RIFFLE ON SUBMERGED PIPE LINE.

broken showed no indication of a flaw at the fracture; the fracture in the second pipe, however, betrayed very porous metal mixed with cinders. These were the only accidents connected with the work, and they could have been avoided easily by subjecting the pipes to a reasonable end pressure; 150 lbs. per square inch or less would have answered every purpose.

In concluding this paper the authors desire to urge all the members who have had experience in laying submerged pipes to participate in the discussion, and thereby contribute the results of their experience to the profession.

EXTRACTS FROM SPECIFICATIONS.

"4. The pipes are to be laid across and under the Willamette River, above the Madison Street bridge, on the line of either Clay or Mill Street, as may hereafter be determined by the Water Committee.

"5. On either line the width of the river is approximately 2 085 ft. at high water, 1 705 ft. at low water, and 1 270 ft. between the harbor lines established by the United States engineers.

"6. High water is produced by floods in winter, and by back water from the rise of the Columbia River during the summer months of June, July and August, and the pipes must be laid during the months of September and October, when the water is low and there is no current in the Willamette River.

"8. An inspector will be appointed by the Water Committee, who shall inspect and test all the materials required for the pipes, and who shall, for this purpose, have free access to the mills or shops in which the work may be performed under these specifications, and the contractor shall furnish, without charge, to the said inspector, specimens and test pieces, in such number and of such forms as he may deem necessary to determine the character of the material, together with the use of the testing machines, and such assistance as may be necessary in handling and operating the same.

"9. The pipes and joints to be in one casting, as shown in the attached drawing.

"10. The metals of the castings must be poured from remelted pigs of good gray iron, without any admixture of cinder, and the castings must be tough, free from cold shuts or blow-holes, of workmanlike finish, and of such density and texture that they may be easily cut, drilled or chipped.

"12. The ultimate tensile strength, by a direct pull, must not be less than 18 000 lbs. to the square inch.

"13. Test bars 26 ins. long, 2 ins. wide, and 1 in. thick, when loaded in the center, narrow sides vertical, and 24 ins. between supports, shall carry a breaking load of not less than 1 900 lbs., and show a deflection of not less than ¼ in. before breaking.

"23. The pipes to be cast in dry sand moulds, placed vertically, and not to be stripped or taken from the pit while showing color of heat.

"The shells to be smooth and sound, without cold shuts, lumps, swells, scales, blisters, sand holes, or other imperfections; truly cylindrical, of full diameters, and with interior and exterior surface concentric.

"25. The pipes when completed, to be thoroughly cleaned inside and outside without the use of acid or other liquid, and then heated to a temperature of 300° Fahr., and immersed in a bath of equal temperature of coal pitch varnish, or other coating material, to be approved by the engineer of the Water Committee.

"26. Each pipe must then be subjected to a test by hydraulic pressure of 250 lbs. to the square inch, and shall, when under that pressure, be subjected to an additional test by a series of blows at various points throughout its entire length, with a 3-lb. hammer attached to a handle 16 ins. long.

"Should any leak or failure in the pipe be shown during this test, it will be rejected.

"35. A trench is to be dredged across the river, not less than 8 ft. below the bottom, or 23 ft. below the level of low water on the portion of the line between the harbor lines.

"38. As the material dredged cannot be replaced in the river, it must be carried away on scows and dumped where it will not interfere with the navigation of the river, or placed within the harbor lines by consent of the owners of the lands.

"39. Payment for dredging will include the removal of all snags, logs, stones and roots which may interfere with the even bearing of the pipes in the trench, and also the removal of any piles which may have been driven near the east or west shores of the river.

"42. Pipe laying will include the work necessary to connect the ball and socket joints, including furnishing and pouring the lead and the furnishing and handling the dredges, barges, scows, and appliances for depositing the pipes in the pipe trench.

"44. After the pipes have been delivered on the pipe-laying barge, each section will be carefully inspected inside and outside, and will then be subjected, in the presence of the inspector of the Water Committee, to a pressure of 200 lbs. to the square inch, and any pipes that shows splits, flaws, leaks, or other defects, will be rejected.

"46. After the pipes have been laid and connected, they will again be subjected to a pressure of 200 lbs. to the square inch for a period of

24 hours, and will then be connected for a period of 90 days with the distribution system of the city water-works.

"47. All defects and leaks in the pipes developed during the test of 200 lbs. pressure, or the connection with the city mains, must be repaired to the satisfaction of the engineer of the Water Committee, or the pipes replaced at the expense of the contractor in case that the repairs cannot be so made.

"48. The work will not be considered as completed or accepted until after it shall have remained in good working order, without leaks or breaks, under pressure from the city mains for a period of 90 days."

DISCUSSION.

E. Kuichling, M. Am. Soc. C. E.—While the speaker had no experience with pipes of this kind under great internal pressures, yet he was familiar with a number of lines of flexible jointed pipe which were subjected to slight external pressures, such as intake pipes laid out from the shore into the deep water of rivers and lakes. A riveted steel pipe of this sort, 5 ft. in diameter and about 1 500 ft. long, was laid last fall under his direction in Hemlock Lake, Livingston County, N. Y., as the intake for supplying the new gravity conduit of the Rochester Water-Works. The pipes were riveted together in lengths of about 100 ft., and provided at the ends with the component parts of ball and socket joints shown in Fig. 2 (page 273). These flexible joints admit of a deflection of 17½° in any direction, and are made mostly of steel plates stiffened with bar, angle and channel rings, cast-iron being used only for the spherical zones or ball portions. The latter were riveted with countersunk rivets to short sections of steel pipe, and then placed in a lathe, where the spherical surface was accurately formed with proper tools. The bearings for this spherical surface are formed of lead, which was melted and poured into the channel rings of the socket and collar after the parts had been assembled in the shop. This style of joint was originally designed several years ago by Mr. William H. Law, of Peterborough, Ont., for use in the 4-ft. and 5-ft. intake pipes of the Toronto Water-Works, and was also adopted for the 4½-ft. intake pipe of the Syracuse, N. Y., Water-Works. Mr. Kuichling.

In its original form, however, the chord subtended by the two lead bearings seemed too short, and in designing the joints used at Hemlock Lake, the chord was lengthened considerably by using angle rings of unequal sides. The joint was also greatly strengthened by the introduction of the heavy steel reinforcement rings above or around the bearings. It should be remarked that all of the steel angle, channel and bar rings were carefully welded, and then riveted together, as

Mr. Kuichling. shown in the drawing. The 5-ft. flexible joints referred to weighed about 6 200 lbs. complete each, the weight of the cast-iron zone or ball portion being about 2 700 lbs. They were made by the Central Bridge and Engineering Company of Peterborough, Ont., at the rate of $290 per joint, including all transportation and attachment to the pipe at Hemlock Lake, but exclusive of the United States Customs duty. The steel plate of the pipe is $\frac{3}{8}$ in. thick where heavy back filling of the dredged trench or channel was contemplated, and $\frac{5}{16}$ in. thick where the back filling was light or where the pipe lies directly upon the bottom of the lake. After the joints had been riveted to the pipes, their weight ranged from 14.5 to 18 tons each, according to the thickness of the plate and the number of stiffening angle rings applied to the pipes where heavy back filling occurred. The pipes were laid in water varying from 20 to 35 ft. in depth, each joint being securely bolted together above the surface of the lake, and then lowered into place on the bottom by means of suitable apparatus. All of the joints appeared to move freely and satisfactorily in every respect, and to be quite water tight. As before stated, the pipe was designed for intake purposes only, and will probably never be subjected to a greater external pressure than that due to about 1 ft. head of water. Slight leakage was therefore a matter of no particular account. There is, however, no reason for believing that the flexible joints here used would not be thoroughly serviceable if subjected to internal water pressure.

In designing such flexible joints, it is essential to proportion the parts so that the bell or socket will not burst under the severe internal pressure developed by the action of a force in the direction of the axis of the pipe. For this purpose the reinforcement of a cast-iron bell or socket with a heavy ring of wrought iron or steel is generally expedient, and has frequently been employed in the past. The use of a long subtended chord and a high versed sine is also very desirable. In the case of the Willamette River pipe, it is stated that a water pressure of 250 lbs. per square inch was applied to a portion of the line, one end of the pipe being temporarily capped. A longitudinal force of about 154 000 lbs., or 77 tons, was thus developed, which tended to pull the joints apart ; and if the radial component of this force at the junction of the socket with the collar be computed, on the assumption that the same is distributed over a width of 3 ins. along the inner circumference of the socket and collar, it will be found that the lead was then subjected to a pressure of about 1 100 lbs. per square inch. For this particular case the half chord is 3.75 ins., and the versed sine 0.355 in. ; but if the collar is also considered, the half chord becomes 6.75 ins., and the versed sine 1.173 ins. These favorable dimensions and the heavy flange of the socket doubtless prevented the loss of more pipes during this severe test.

The pipe was laid in September, when the water was comparatively

Mr. Kuichling.

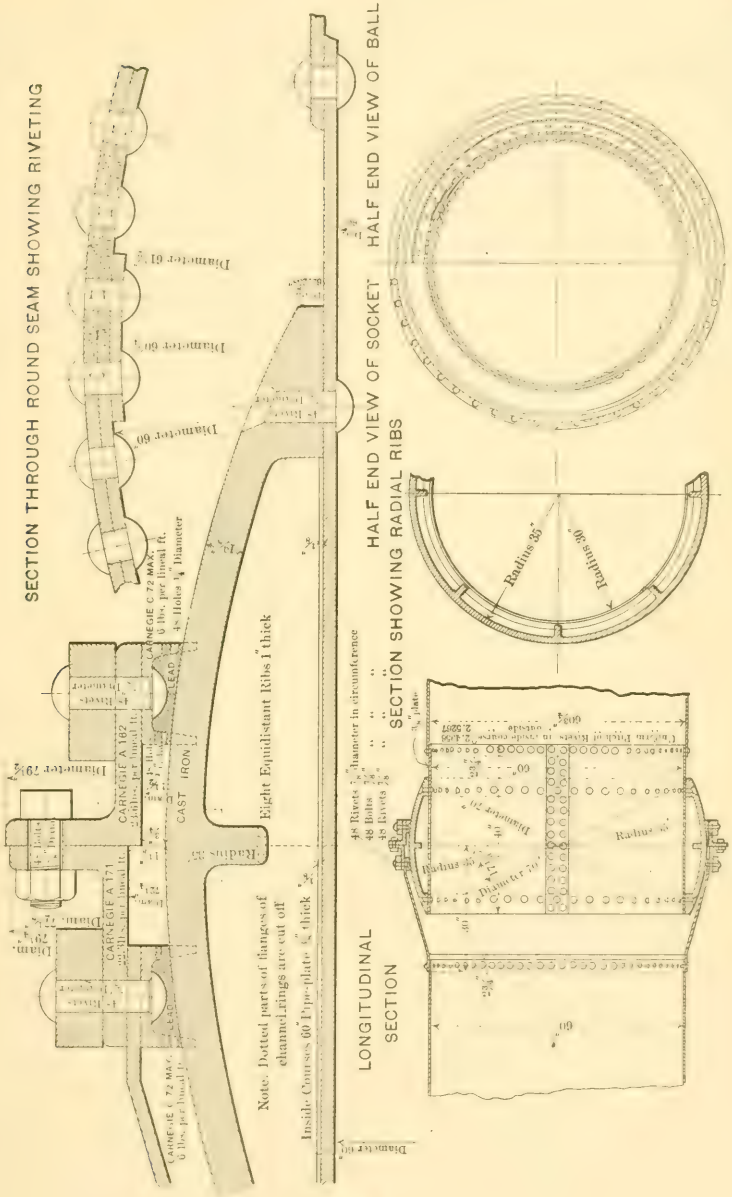

LONGITUDINAL SECTION
SECTION THROUGH ROUND SEAM SHOWING RIVETING
HALF END VIEW OF BALL
HALF END VIEW OF SOCKET
SECTION SHOWING RADIAL RIBS
LONGITUDINAL SECTION
Eight Equidistant Ribs 1" thick
Note. Dotted parts of flanges of channel rings are cut off
Inside Courses 60 Pipe-plate ⅝" thick
CARNEGIE A 182
CARNEGIE A 171
CAST IRON
Radius 35"
Radius 30"

FIG. 2.

Mr. Kuichling. warm, and the joints were pulled to a tight seat by the great longitudinal force above named. Assuming that a fall of 25° Fahr. in the temperature of the water will occur in the following winter, a contraction or reduction of length amounting to 1 in 6 500 in the cast-iron pipe will occur, which will produce another powerful longitudinal force. If the lead in the joints be regarded as unyielding, this force will be about twice as great as the one caused by the aforesaid test pressure, which produced a stress of about 1 100 lbs. per square inch in the lead packing; hence the contraction will cause a stress of about 2 200 lbs. per square inch on the packing, whereby the metal will probably yield or flow. The socket flange should therefore be proportioned to resist a pressure of from 1 800 to 2 000 lbs. per square inch, which seems to be the point at which lead begins to flow; and it is evident that this has been done in the case of the Willamette River pipe.

The remarkable tightness of the joints in this pipe is very gratifying, and it is to be hoped that other experiments will be recorded which will bring out more fully the merits and reliability of such constructions. It may be urged that while a pipe line of this kind may be tight when first laid, the effect of changes of temperature will eventually give rise to leakage at the joints, and it would be interesting to learn whether such leakage varies with the seasons, being more in summer and less in winter.

The speaker called attention to an interesting account of the manufacture of the pipe and flexible joints at the foundry, given in *Iron Age* of January 10th and 17th, 1895.

Mr. McCann. Thomas H. McCann, M. Am. Soc. C. E.—About 14 years ago, during the laying of a 20-in. force main of which he had charge, it was necessary to submerge the pipe across two tidal rivers, each being about 400 ft. wide, with firm mud bottom and slopes of about 12 in 100, the range of tide being about 5 ft. There was no dredging done. "Ward" joints were used, the calking being done on one shore and the pipe then hauled across the river as each joint was completed, a 40-H. P. engine and heavy chains being used for the purpose. As each joint entered the water, two ordinary standard oil barrels were lashed firmly to the pipe which served to buoy it. When the end of the main had reached far enough up the opposite shore to allow for the extension due to settlement, the barrels were gradually cut loose, and the pipe settled slowly to the bottom. After the water was turned on, a diver was sent down to examine the joints, but he found no leaks. The pressure was about 90 lbs. to the square inch. The maximum depth at high tide in both rivers was 21 ft.

The main has been in constant use during the last 14 years, and an examination made by a diver each summer shows that no leaks have occurred. The pipes are now about half their diameter in the

mud. At one of the banks where the main enters the water down a steep slope of about 30°, one joint on the edge of the shore has pulled out about 2 ins. The time occupied in submerging the main at each river was about a week. Mr. Miles Tierney was the contractor. Mr. McCann.

L. L. Tribus, Assoc. M. Am. Soc. C. E.—It is a source of regret that the authors have not given the cost in a little greater detail. It would be of interest to know the exact cost of the 28-in. line. Such work is usually done under contract, and while the total cost may be known, just what the profit or loss was to the contractor cannot be ascertained. Mr. Tribus.

The speaker had recently laid a line of 12-in. pipe on the ice in Morris Lake, New Jersey, and knew the contract price, and about what the actual cost was as well. The ice was some 10 to 14 ins. in thickness. A Ward spherical joint was used every 48 ft., there being two lengths of pipe with ordinary bell joints, then a pipe with a Ward spigot, then one with a Ward hub, each length being 12 ft. long. These were laid on the ice, blocks being put underneath and ropes fastened to a tackle on both sides of the pipe. It was then lowered in water from 6 to 12 ft. in depth, about 50 ft. at a time. After it was laid, it could be seen gradually settling in the mud, owing to the clearness of the water. It seemed to go down very successfully, but tests, to be applied later, can only determine the leakage. This line was about 1 400 ft. long, the pipes averaging about 1 000 lbs. per length. The other line was about 700 ft. in length, laid in water from 10 to 24 ft. in depth, going down equally well, apparently with very little leakage. The question of leakage is comparatively unimportant, as the pressure is very slight and the supply very abundant. The two lines will eventually be connected through a masonry dam, and form the upper or intake portion of the delivery main for supplying Newton, N. J., some 8 miles away.

J. J. R. Croes, M. Am. Soc. C. E.—The expression of cost in terms of amount of material and amount of labor is a great deal more satisfactory than in dollars and cents. If the amount of labor and of material is known, an estimate can be made under local conditions, whereas amounts given in dollars and cents are no criterion for the actual cost in another locality. Mr. Croes.

He was inclined to agree with the authors in the matter of delays and disputes arising from conflicts of inspection. It appeared that the inspector at the shops, several hundred miles away, passed certain pipes which were accepted by the company, and after transportation across the continent were found to be, according to the local inspector, somewhat out of true, and it was only by taking the risk and accepting the responsibility that the contractors were able to finish the work in any reasonable time. He thought that the contractor in this case took a very proper ground.

Mr. Emery. CHARLES E. EMERY, M. Am. Soc. C. E.—His experience was confined to laying pipe with ball joints in trenches on land instead of under water, but he had been much interested in the work of Mr. Ward and others, who had succeeded in constructing water pipe which was flexible while being laid and would remain tight under practical conditions. Referring to the defects mentioned in the paper, he considered from his own experience that it is as easy to turn a ball as to face a plane surface. The tool has but to be guided in a circle and properly set, and the surface operated upon will be spherical. Details are important; for instance, it is necessary that the point of the tool be at the level of the lathe centers, and, in case the tool be carried by a revolving tool-rest on the lathe bed, that the center of this rest be in the center of the shears, or in the vertical plane of the lathe centers; also, that by this method the point of the tool must be at the right radial distance from the center of the tool-rest. When laying the steam pipes of the New York Steam Company he had placed a globular joint every 40 to 50 ft. to remove all strains due to changes in line or grade, and there never was a particle of trouble with any of them. The joints were made in that case with very thin copper, covered with a thin coat of paint, and on breaking such a joint contact was shown all over the abutting globular surfaces. There should be no more difficulty, with proper tools, in obtaining spherical surfaces as accurate as ordinary plane surfaces, as it only requires intelligent inspection, based on knowledge of the way work is practically done in a shop. The inspector must not only be familiar with the result to be attained, but, as a safeguard, he should for unusual details examine the construction and method of operation of the tools, when, with reasonable care, the work will be right. The apparatus used for turning the globular joints of the Steam Company consisted simply of a link of the proper radius hinged at one end to an ordinary traversing tool-rest and at the other to a stationary frame, the traversing screw having been removed. With this construction the tool-rest had only to be fed longitudinally by the motion of the carriage along the lathe shears when the transverse motion required to give circular movement to the tool and form a globular surface was furnished by the swinging of the link.

Billiard and other balls are turned by means of a revolving cutting tool on an arbor transverse to the axis of the lathe, the stock operated upon being meanwhile revolved in the ordinary way.

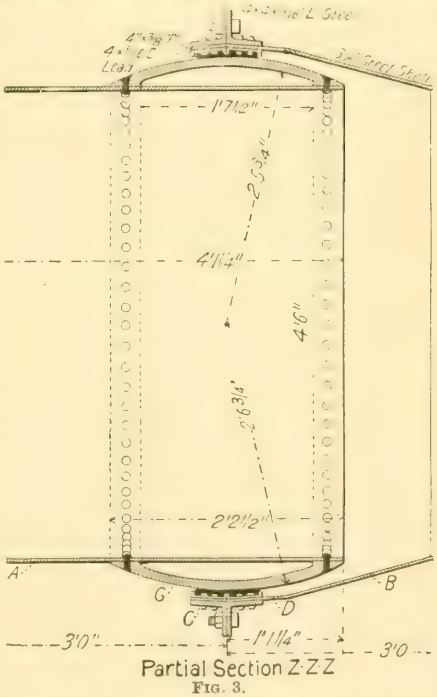
Mr. Crowell. FOSTER CROWELL, M. Am. Soc. C. E.—In 1868 or 1869 a submarine main was laid across the Schuylkill River with flexible joints that must have been one of the very first instances of the use of the Ward joint. No cradle was employed in laying the pipe. It was lowered from scows, there being several unsupported joints at the tail end of the laying part. The pipe supplied a high-service storage reservoir

and the pressure was very considerable. The pipe was the sole dependence of the reservoir, and he believed that the joints proved entirely satisfactory. Mr. Crowell.

In the Ward joint practical water-tightness seems to be secured without the additional refinement and cost of manufacture advocated by some eminent engineers, to secure perfectly fitting spherical surfaces.

E. Sherman Gould, M. Am. Soc. C. E.—He had no experience in this kind of work, although he had laid a great deal of pipe. He quite agreed with Dr. Emery in saying that a little additional trouble in the shop would save a great deal of trouble afterwards. If the lathes are properly adjusted it is just as easy to turn the pipe perfectly true as not to do so, and he could see no reason why a little extra trouble should not be taken at the start and avoid all the difficulty which seems to have occurred in this case. Mr. Gould.

Frank W. Skinner, M. Am. Soc. C. E.—A simple contrivance for turning flexible pipe joints was installed for the manufacture of the riveted steel submerged intake pipe of the Syracuse Water-Works. This pipe was built by the Groton Bridge Company, which provided some special plant for the construction of the 54-in. straight pipe of which there was about 6 500 ft. laid in water from 15 to 40 ft. deep in rigid sections about 116 ft. long. These were connected by universal joints that permitted a deflection of several degrees in any direction, and were lowered, one at a time, by derricks on large anchored barges. The joints were made as shown in Fig. 3 by a cast-iron spherical segment *G*, riveted to a section *A* of the 54-in. pipe. This end was received in a conical steel piece *B*, bolted at the other or small end to a regular section of the 54-in. pipe, and making a tight sliding contact on the casting *G* by a lead packing *D*, held in a stiff riveted annular socket *C*. Mr. Skinner.



Partial Section Z-Z-Z

Fig. 3.

Mr. Skinner. In order to turn the spherical surface of casting *G*, a simple machine was designed and constructed by the shop superintendent at a

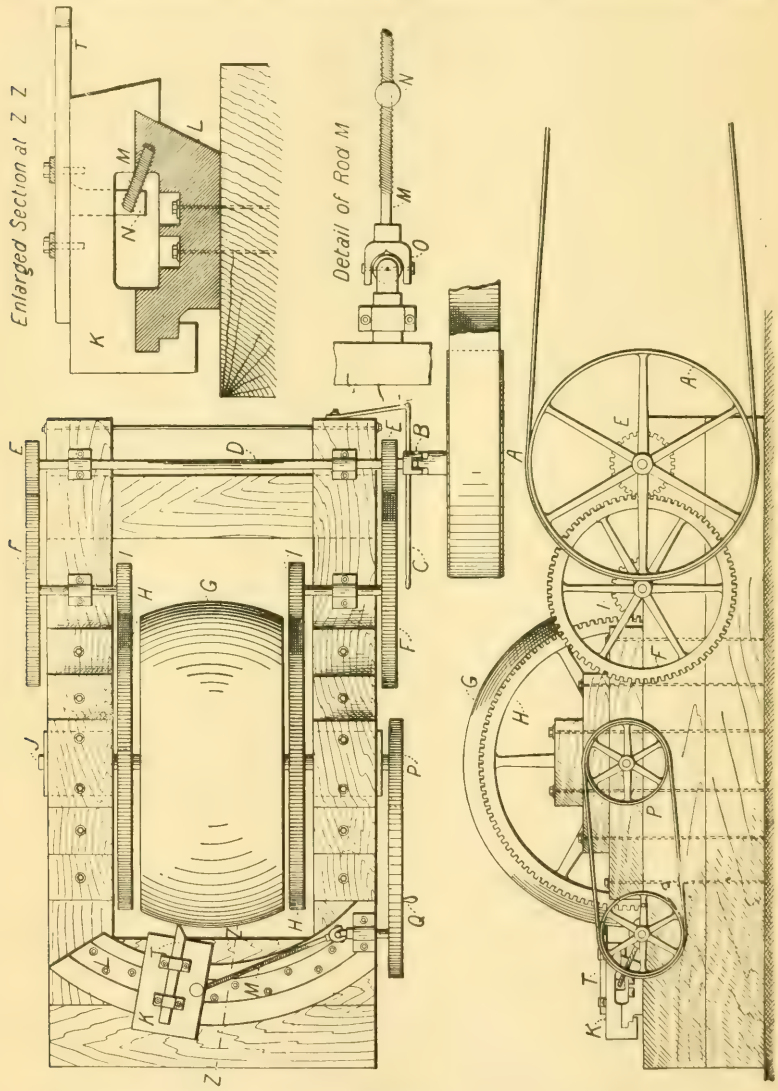


FIG. 4.

cost probably not exceeding $50. Fig. 4 shows the general arrangement and operation without exact scale or dimensions.* The machine

* See the *Engineering Record*, Feb. 9th, 1895.

was made with old gear wheels, etc., which happened to be in stock. Mr. Skinner.
It was solidly set in a heavy timber frame and was operated by the lever *C* commanding the clutch *B* which engaged the loose-running driving wheel *A*. The spherical segment *G* was secured to the shaft *J*, which was turned by double sets of gears *H*, *I*, *F*, *E*, driven by the shaft *D*.

The tool *T* was set in the carriage *K* which traveled on the circular arc of the track *L*, concentric with the sphere. The tool was automatically fed by the screw-rod *M* turning in a nut *N* in the carriage *K*. A belt from the pulley *P* of the shaft *J* to the pulley *Q* actuated the rod *M* through the knuckle joint *O*, and a handle was provided for backing it up quickly.

CORRESPONDENCE.

JOHN F. WARD, M. Am. Soc. C. E.—The first trouble mentioned in Mr. Ward.
the paper was, "that the ball ends of the pipes had not been finished to a truly spherical surface." The method of inspection by micrometer measurements as used in finding the amount of imperfection in form, is called by the authors "crude," but, perhaps, "badly chosen" would convey the idea better. Attention is called to a far simpler method of detecting the inaccuracy of the zone of a sphere, which is to use a plain ring of suitable size (which in this case would be about 18 ins. in diameter), bored and faced truly in a lathe. This, if simply laid on the alleged spherical part of the pipe, will show by its contact whether there are any high places, and a flat space of 1½ or 2 ins. in width would show in a rather startling manner, without the work of calculating the ordinates of the curve.

The experience gained in this work shows clearly that the bad turning of the ends of the pipes did not in any degree prevent a very good result, and the securing of a reliable and, in every way, first-class job. The apparatus used for depositing the pipes in the trench and the method of operating it was not new; it was clearly shown in *Engineering*, Vol. XI, page 398, London, 1871.

He thought the starting of 650 ft. of the line of pipe, weighing 200 tons, by a water pressure of 250 lbs. per square inch in the pipe, an interesting piece of experience, as it shows a static friction on a sand and gravel bottom of considerably less than 50% if the joint at the large end of the reducer was the one which was started by the pull, or less than 38% if the small end was the one that moved.

If both joints were equally well made, the larger one being the stronger only in the proportion of, say, 100 to 87, and the relative proportionate pull being as 100 to 76, the larger joint should have moved.

Mr. Duane. JAMES DUANE, M. Am. Soc. C. E.—He had laid a number of lines of submarine water pipe, under various conditions, and is now making a design for a 36-in. flexible-jointed main. The paper is of great interest, especially the sketch and description of the cradle used, but he believed that the form of joint employed by the authors is in every way inferior to either the regular Ward joint or to that designed by himself and adopted as standard by the Croton Water Department, New York.

The fact that two of their joints failed under the pull due to the pressure used in testing shows structural weakness that would have been fatal to the success of a line laid under the extremely unfavorable conditions that are sometimes encountered here.

It is questionable if the convex ball spigot can be as readily or accurately turned truly spherical as can the concave hub, still the excessive accuracy demanded by the Chief Engineer of the Portland Water-Works seemed to be unnecessary, and unattainable at any reasonable cost. The writer never demanded nor expected such close work, and never had any trouble as to perfect flexibility; and granting that slight imperfections in the spherical-turned surface may cause leakage when the joint is rotated, it must be remembered that the tightness of joints of this form is dependent on their being laid on their final bed under a strong tensile strain. This practically calks the entire lead joint at one operation, and, as the lead is sufficiently ductile to fill all reasonable irregularities, and sufficiently inelastic to remain where put, the slight departure from theoretical form cited is of no practical importance.

He also differed from the authors' statement that "the advantages in favor of the long pipes are obvious." His experience had been that the greater the flexibility, viz., the shorter the pipes, the less the strain on each joint in laying, and the better the line accommodates itself to irregularities in the bed. In the first line laid 12-ft. lengths were employed which he had since reduced to 9 ft. as a standard, while in some cases, where extra flexibility was required, 6-ft. lengths were used to good advantage. For splicing breaks, lengths as short as 4 ft. have given excellent results on account of ease of handling and shortness of curve.

Although the first cost of short pipes is greater, they are preferable because of the greater certainty in laying and the avoidance of necessarily expensive repairs, especially those involving the employment of a diver, and amply repay for the small additional cost; while, in case repairs do become necessary at any time, the more flexible the line, the more expeditiously and cheaply can they be made.

A main he had laid to Ward's Island embodied all the good points and remedied the defects brought out in an extensive experience. The special features of this design are the wrought-iron reinforce

band shrunk over the hub, and the rounding off of the sharp cutting edge at *B* (see Fig. 5). This band, when properly proportioned and shrunk on, absolutely insured the hub from bursting against any tensile or cross-strain to which it could reasonably be subjected. Mr. Duane.

In repairing a line on which a large vessel had sunk, it was necessary to break the pipe in several places in order to obtain free ends to splice. To accomplish this, the powerful derrick of a wrecking boat was used, and the joints parted either by the spigot shearing through the lead joint, or, in case of sharp bending, by the crumbling away of the inner edge of the hub at *B* to a sufficient extent to allow the spigot with its lead ball to escape. In no case was a hub split, which is the usual method of failure with the ordinary cast-iron pipes.

In the first pipe line laid, the sharp cutting edge was left just as it came from the planer. It was soon found, however, that when the

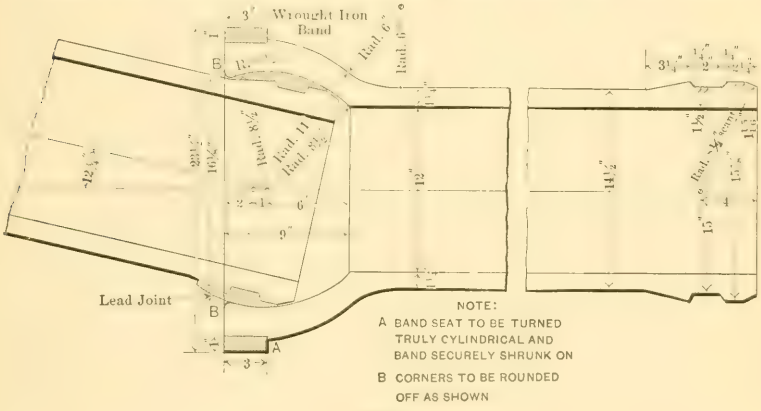


FIG. 5.

joint was rotated, this sharp edge itself acted as a plane and took off a shaving of lead at each motion, with the result that it was extremely difficult to pull the joints tight afterward. The rounding above mentioned obviated this difficulty satisfactorily.

The following brief description of the worst break he has yet had to repair illustrates the facility with which this form of pipe may be handled even under unfavorable conditions.

A 12-in. line laid across the East River (Hell Gate) to Blackwell's Island parted in about 70 ft. of water, where the great depth of water, the irregular, rocky bottom and the great velocity of the current (6 to 8 ft. per second being common), all combined to make the work one of special difficulty. The intervals of slack water were so short that a diver could work only about 30 minutes to a tide, and it took him two days to locate the break. It was found that one of the wrought-

Mr. Duane. iron bands had parted, owing to a defective weld, and that the unsupported hub had then split, permitting the line to pull apart. This is the only accident due to this cause that he ever had. The broken ends were brought to the surface about noon, and before night the splice had been made, by inserting six 4-ft. lengths, the pipe lowered into place, and the water turned on.

In lowering the pipe a strain was kept constantly on the right of the pipe line and the scow allowed to sag down stream, thus pulling all the joints taut in the shape of a horizontal bow. This occurred four years ago, and the pipe has worked all right ever since.

The cost of these lines laid has varied from $7 to $11 per linear foot, dependent upon the price of iron and the natural difficulties to be overcome, amount of dredging, excavation, etc. This price includes all labor and materials complete, with a one-year guarantee. This form of joint had been thoroughly tested, and he could recommend it as being economical in first cost, and as thoroughly efficient. It is not patented.

In closing, he wished to ask the author the following questions: How were the joints run? Was the rib cast on the inside of the hub an efficient stop against the lead running through, or was a yarn gasket, clay dam or other similar device employed? Were the joints run and calked in two separate operations, as described by Fanning? His experience had been that the lead should be run at one pouring to make a homogeneous joint, and that this is more essential than is calking to insure against leakage. If the pipe is laid under a suitable tension, calking may be omitted entirely without ill effects.

Mr. Dunham. H. F. Dunham, M. Am. Soc. C. E.—The paper, although a valuable one, is unlike many others in being too brief. A paragraph or two in relation to the main channel, the amount of shipping for which provision had to be made and the controlling factors in the design of the work would have been acceptable, as also a few general facts in regard to cost, such as the difference in price per ton between common pipes and the pipes purchased, the cost of lathe work, cost of cradle, etc. While the work was undoubtedly carried out to the satisfaction of the parties interested, still questions naturally arise which may be without the province of the authors to answer; as, why, for instance, were the elaborate cradle and its appurtenances constructed? Why was each joint a flexible one? Or, why were any flexible joints at all introduced? And, why was the integrity of an important line left dependent upon the threads of 1-in. iron bolts and nuts which may be exposed in the river bottom to corrosive substances? It does not appear from the description of the material in the bottom of the river that any movement of the pipe due to shifting channels or any other cause is to be anticipated. The description and the sketches alike fail to show any reason why a submerged line could not have

been laid with common pipes and bell joints, each one of which would be as good as joints made on dry land and a few of them rather better than such ordinary joints. For nearly 10 years, work of this kind has been successfully and cheaply carried out by contractors in this country for river crossings, lake intakes, etc. Nothing more plainly shows the difference in the two methods and the great advantage of the modern way than the attention given to tests as the work went on. Had the line been laid in sections with rigid joints the test would have been scarcely more worthy of remark than would the test of the same length of that size of pipe laid in dry ground. The work described appears to have been important enough to warrant exact information in regard to its condition. If a leaky gate prevented this it would have been worth while to repair or replace it. Too much stress seems to have been placed upon exact measurements of parts, and too little upon the relation those parts were to sustain to the whole work. Mr. Dunham.

It would be of interest to know whether gravity or the barge assisted when the joint at the reducer was drawn out $\frac{1}{4}$ in., and how the proper endwise strain or pull upon the submerged line was continued when the connection was made with the larger pipe at the completed end. An end pressure test for each pipe is referred to as having been omitted, and although the conditions for testing are not fully described, it would appear that each length, or at least the greater portion of it, must have been subjected to an endwise stress of 400 or 500 lbs. to the square inch while in the testing machine. The greater area of the bell end insures this.

The flexibility of a line of cast-iron pipe as ordinarily laid is greater than many suppose. A 10-in. pipe of the writer's design across a river 1 000 ft. wide with abrupt banks, was put together with bends and common joints so as to conform to the dredged channel, then tested and lowered into place by means of screw rods operated by a dozen men. The first man gave his hand wheel three turns and then went to the next, two lengths beyond, which he also turned three times, and at the same time the man who followed him gave the first wheel three more turns, then three men, four men, etc., followed until all were at work and carried an undulatory motion or wave in the line pipe back and forth across the river until it was lowered about 10 ft. While still suspended, fine rip-rap was filled into the trench, to insure a good bearing. No diver was employed. This pipe line seemed perfectly tight, as it held up the gauge pressure. This was six years ago, and no trouble has yet occurred. The pressure varies from 60 to 140 lbs. It is not, however, implied that heavy work should be done in this manner.

Bolton W. De Courcy, M. Am. Soc. C. E.—The complete success of the means and plan prepared by the authors and so well described by them makes a very interesting paper. Mr. DeCourcy.

Mr. DeCourcy. It is a mistake not to have a strict examination of all materials before they are sent from the factory. A contractor is very often put to great inconvenience by inspection on the ground. Without packing it is very difficult to make a perfectly tight joint at such severe pressure as the tests required. It is unnecessary to exceed the normal pressure so extremely as in the work mentioned in the paper; in fact, it might be detrimental.

There is a good recommendation for our western timber in the reference to the length of the timbers used in the cradle, 100 ft. The Pacific slope is certainly favored in the size and quality of its forest trees. The company represented by the authors is to be congratulated on every difficulty being so well met; and in the short time for the completion of the work governed by the phenomena of the river and also unseasonable rain, proof is presented of completeness of design, as well as pluck, energy and ability.

Mr. LeConte. L. J. LeConte, M. Am. Soc. C. E.—The ball joint adopted is of excellent design in many respects, but rather too expensive for common

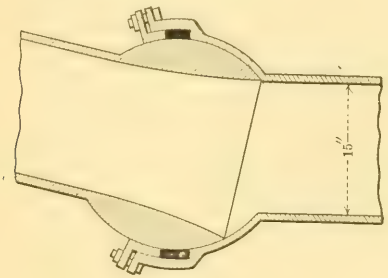


Fig. 6.

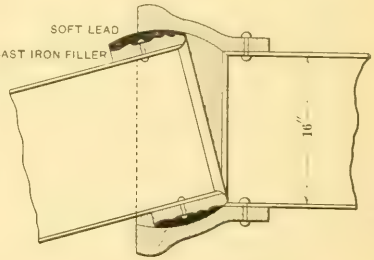


Fig. 7.

use, there being too much nice turning required. The most useful ball joints of to-day are but modifications of the old ball-and-socket or universal joint invented by Mr. James Watt for the Glasgow Water-Works Company in 1810, which laid in that year an inverted siphon 1 000 ft. in length across the River Clyde. This was of cast-iron 15 ins. diameter in 9-ft. lengths with flange joints, and had ball joints interposed at variable distances, depending upon the profile of the bottom of the trench. The length of the sections between ball joints was generally 28 ft. 6 ins., except at the middle of the line, where a single 10-ft. length became necessary in order to fit the ground. The ball surfaces were not turned at all, being made watertight by means of an adjustable packing joint similar to an ordinary stuffing-box.

The details of Watt's 15-in. siphon ball joint are shown in Fig. 6. This pipe line was laid on strong frames, made of parallel logs; these frames were joined by strong iron hinges, having their pivots in hori-

zontal lines at right angles to the axes of the pipes and passing through the centers of spheres, of which the zones of the sockets are portions. The flexible joints are at the extremities of the frames. The frames and pipes were put together in succession on ways situated on the south side of the river, and, the open or north end being plugged, were hauled into and across the bed in a trench prepared for them. The hauling machinery was, of course, on the north bank. The operation was quite simple, being aided by the flotation of the framework and the buoyancy of the empty siphon, assisted and directed by pontoons. The movable joints and hinges of the frames allowed them to conform to the bed

Mr LeConte.

The water company put in another siphon, 18 ins. in diameter, in 1830; a third siphon, 25 ins. diameter, in 1838, and a fourth siphon, 40 ins. diameter, in 1840. All of these were put in under the same plans.*

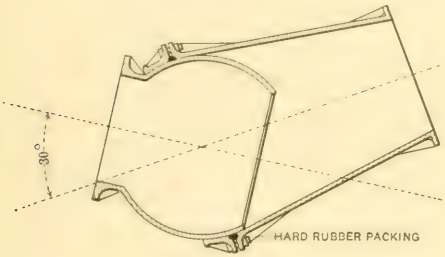


FIG. 8.

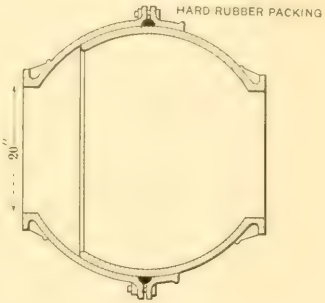


FIG. 9.

The longitudinal "pull" mentioned by the authors always exists more or less and invariably tends to tighten the ball joints. In case of wrought iron and steel pipe this "pull" is also partly due to swelling of the pipe under high pressure. In extreme cases the shortening of the pipe line is quite marked.

Leakage at the top of the ball joint under low pressure is almost universally the case with the larger sizes; but if the joints are made with ordinary care, high pressure (60 lbs. say) is ample to force the balls back to their bearings and thus stop leaks due simply to slight looseness in the socket or packing.

The device adopted for laying the pipe line was admirable, and an improvement on that used by the Spring Valley Water Company, of San Francisco, Cal., in laying a double line of 16-in. pipe across the upper part of San Francisco Bay. This double siphon was 16 000 ft. long, the depth of water being 50 to 60 ft., with strong tidal

* See "The Life of James Watt," by M. Arago, 1833.
"History of the Water Supply to Glasgow," by John Burnet, 1869.

Mr. LeConte. cross-currents and at times some very heavy seas. The ball joint adopted for this work is shown in Fig. 7, and was very cheap and efficient.

Where the siphon is subjected to sharp bends, a good deal of head is lost by friction at the ball joints. This difficulty is greatly relieved by the modification introduced in the Badois joint (Fig. 8), in which the rear portion of the socket or casing is made in the form of a long frustum of a cone. This reduces friction very much. The von Schmidt joint is shown in Fig. 9.

Mr. Schuyler. JAMES D. SCHUYLER, M. Am. Soc. C. E.—In June, 1893, the writer was called upon to make a report to the Water Committee of the city of Portland, on the subject of the most desirable method of effecting the crossing of the Willamette River with the pipe which forms the subject of this paper, and was engaged in planning and constructing the system of distributing reservoirs in connection with the same plant at the time the work of laying the pipe was performed. The first examination, to which two weeks were devoted, demonstrated that considering the elements of time and cost of governing, no other method of effecting the crossing of the river was practicable, but to lay a flexible-joint submerged pipe under the river-bed. The possibility was contemplated of using one of the four existing bridges spanning the river to carry the pipe, submerging it only at the short draw span, but as none of them had been designed to carry such an extra load the plan was manifestly impracticable. But for the lack of time to organize and combine with the city and county for the purpose of constructing jointly a new bridge designed for the purpose, and located about 1 mile up the river from the highest existing bridge, where high bluff banks admit of erecting a bridge high enough to clear river craft at all stages of water, that plan of crossing would have appeared the most desirable. The pipe would then have been accessible at all times, and the ordinary cast or wrought iron pipe could have been used, while the maximum pressure might have been reduced some 40 lbs. per square inch by having the entire pipe nearer the hydraulic grade line. This plan not being feasible, the submerged pipe laid in a trench to be dredged some 12 ft. deep in the river-bed was the one recommended, substantially as previously planned, but with the following modifications of the plans :

First.—The diameter of the river section was reduced to 28 ins., or if two pipes were considered desirable as a measure of precaution, both were to be 28 ins. in diameter, but laid 100 ft. apart, that the breaking of one might not undermine and destroy the other.

Second.—The total length of flexible pipe was shortened by laying it only to the low water-line on each side instead of to the high water-line, thus effecting a considerable saving in distance of the more expensive pipe.

Third.—The pipe was to be made of wrought steel, with butt joints on the longitudinal seams, and cast-iron ball and socket joints. The balls were to be turned and fitted in the shop, joints poured and one end riveted, the work in the field to be only the riveting of the other end. Bids were to be taken also on aluminum bronze ball and socket joints. Mr. Schuyler.

Fourth.—The location of the crossing was to be changed from Clay Street to a line extending from the foot of Stephen Street on the east side to the foot of Mill Street on the west side, which location is 500 to 800 ft. higher up the stream.

Fifth.—Y branches and valves were to be placed on the main at some convenient points above high water-mark on each side of the river, for connection with a second pipe to be laid either across a high bridge, if such be built, or under the river, 100 ft. away from the first pipe.

The reasons given for these recommendations, which were accepted by the Chief Engineer, and adopted by the Committee upon his report, were in substance as follows: The reduction in diameter from 33 ins., which had been fixed upon for the diameter of a single line of pipe subsequent to the rejection of bids upon a double line of 24-in. pipe, was recommended because it could be accomplished without materially affecting the capacity of the main, and for the reason that without changing the thickness of the metal the strength could be increased in the ratio of 7 to 6, and the weight reduced 10 to 12%, enabling the pipe to be handled with greater facility and reducing the chances of accident. The capacity of the main to the high-service reservoir was computed at 22 325 000 galls. daily, in full section throughout, or 21 800 000 galls. with the submerged section reduced to 28 ins., while if delivery were made at the low-service reservoir direct, where at least 85% of the West Side water was to go ultimately, the capacity, even with the reduction in diameter at the river, would be about 28 400 000 galls. daily, which is greater by 3 000 000 galls. than the entire capacity of the Bull Run pipe, which has to supply both sides of the river. The only reason for the delivery of the low-service water through the high-service reservoir on the West Side, is to utilize the power afforded by the drop from high to low service for pumping a small supply to levels 500 to 600 ft. higher, which power can at any time be replaced by steam, and the pipes left to deliver their utmost capacity where it may be needed regardless of the power question.

The preference given to wrought steel over cast-iron was chiefly on account of the longer lengths and fewer joints with which it might be laid, and under the supposition that 13 ft. was about the longest length at which cast-iron pipe was ordinarily made. The contractors succeeded in obtaining cast-iron pipe in 17-ft. lengths, which reduced the number of joints supposed to be necessary by 23 per cent.

Mr. Schuyler. The change in location was recommended because it was manifestly a better line in many respects, with a more uniform and firmer bottom, with coarser gravel, less liable to scour, requiring less dredging for the pipe-trench, having better approaches, beside being somewhat shorter.

Specifications were prepared in accordance with these recommendations, but calling for bids on cast-iron pipe in addition to the steel pipe, the result of which was that the lowest tenders for cast-iron being about $14 000 less than the lowest bids for riveted steel, the cast-iron was given preference, chiefly, if not solely, on economic grounds.

The bids for steel pipe ranged from $68 000 to $164 640, the latter being the bid for aluminum-bronze ball and socket joints with steel butt-joint riveted pipe. For cast-iron the bids ranged from $54 000 to $113 580. The prices asked for laying varied from $2 50 to $19 per foot. The increased cost due to the revision of the bid of the Oregon Bridge Company referred to in the paper, amounted to about $13 000, and this and some extras brought the total cost of the submerged pipe, 2 000 ft. in length, up to $79 885.

The saving to the city which can be directly traced to the recommendations of the Consulting Engineer on the basis of the contract prices, amount to about $40 000 over the double line of 24-in. pipe which had been contemplated, or about $25 000 over the single line of 33-in. pipe, a circumstance which is referred to without any desire to claim any special merit or achievement, but as indicating the value of calling an outside engineer in consultation, one who can view local conditions with new eyes and from a different standpoint.

The successful laying of this pipe under numerous difficulties was a creditable piece of work, and the mechanical appliances employed were ingenious and well planned. The cradle on which the pipes were laid while the joints were being poured, and down which they slid to the bottom on a true 10° curve, was specially applicable to the conditions of this case, although in rougher waters or with depths over 40 to 45 ft., such a cradle would be too severely strained to be practicable.

The authors refer to the fact that during the experimental tests of the first joints laid out from shore "the leakage was in every case confined almost entirely to the upper portion of the joint, the extreme lower portion being tight," and suggest that this was the result of the extreme weight of the pipe, "which the most accurate workmanship could not overcome." As the surface area of the lead in the lower half of the pipe is about 592 sq. ins., the weight of the pipe when lifted 4 ft. at one end might produce a compression of the lead to the extent of about 0.008 in., which would leave a space sufficient to account for considerable leakage, provided the pipe rested in lead alone; but, unfortunately for that theory, the projecting flange or ring of cast-iron inside the bell, which forms the back wall for the lead in the joint (see Fig. 1, page 258), acts as a rest and a centering ring for the spigot end

of the male pipe, and would prevent any such compression in the lead, or any perceptible compression whatever. For this reason it seems that the chief cause of the leakage at the top of the joint, which was observed before as well as after the pipe had been raised and lowered, arose from sponginess in the lead, due to confined air in the lead space, caught during the pour without sufficient vent or escape, as well as to insufficient calking, due to the great depth of the lead. Mr. Schuyler.

The method adopted of pulling the joints tight by bolting on a head or flange and subjecting it to very high pressure at intervals of about 200 ft. during the process of laying was so palpably effective that it overcame all objections raised to the roughness of the turning of the balls. The pressure was sufficient to produce a more perfect calking of the lead than would have been effected by any other available means.

The question raised by the paper is as to whether this is a customary or desirable method of procedure in laying submerged pipes, and also as to whether greater perfection in turning is not ordinarily sought and attained than was given to the balls in this case. The double line of 16-in. pipe laid by the Risdon Iron and Locomotive Works, in 1887, for the Spring Valley Water Company of San Francisco, across the Bay of San Francisco, was made with joints so perfect that when tested in the shop, under pressure as high as 500 lbs. per square inch, and turned at all angles with the pressure off and on alternately, no leakage whatever was observable; hence it was not necessary to resort to pulling on the joints, by using high pressure at frequent intervals while laying, to make them tight after laying. In this joint hemp packing was used, and to its use much of the excel-

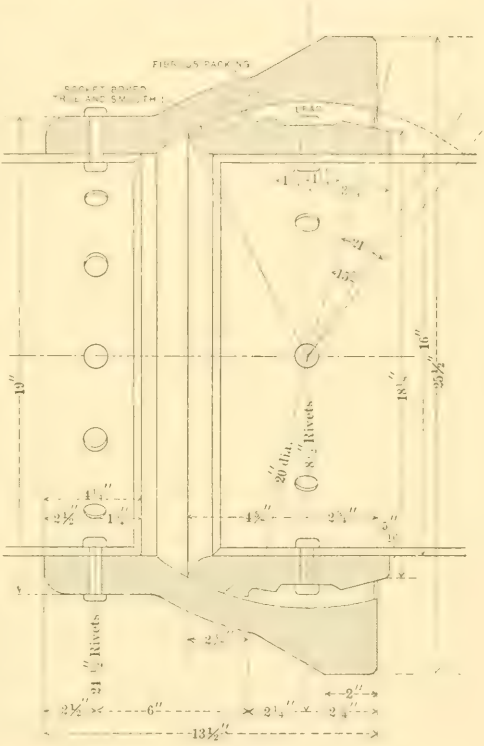


FIG. 10.

Mr. Schuyler. lence of the joint has been attributed. The construction and laying of this pipe is described in a paper* by R. S. Moore, Superintendent of the Risdon Iron and Locomotive Works, from which the following facts have been gleaned : The distance from shore to shore was 6 500 ft., of which 2 000 ft. in the center was from 50 to 60 ft. in depth. During the laying they experienced much rough weather, and at all times had to contend with a tidal current that was often as strong as 6 miles an hour. The motion of the vessel during time of high winds was occasionally so great as to prevent the pouring of the joints, and to compel the workmen to suspend work until the weather moderated.

The barge from which the pipes were laid was held in place by taut cables, anchors and a firm lashing to the pipes, that were suspended always slightly above the shute where the pipes entered the water. No divers were employed, nor was the pipe pulled at all by applying pressure. (At Portland a diver was constantly employed calking joints under water.) Both pipes were laid simultaneously, side by side, in lengths of 18 to 19 ft., and consisted of lap-welded tube, galvanized or "kalameined," and double dipped in asphalt, the joints being made in cast iron, riveted to the tube (see Fig. 10).

The author of the paper quoted, in a recent letter in reply to an inquiry, writes as follows:

"Our idea in designing this joint was to have one which would permit of sufficient deflection while the pipe was being laid, and which would be absolutely tight when the pipes were straightened out on the bottom of the bay. The joints we used accomplished this purpose to our entire satisfaction, and we were, therefore, not compelled to resort to the method used at Portland of pressuring the pipe in order to make it tight. The writer thinks it would have been impracticable to have put pressure on any of the Spring Valley pipe during the time it was being laid. The effect of doing so would be to set all the joints, including those in suspension from the barge, as well as those on the bottom of the bay. This should not be done. From the papers received it would seem that the method pursued by the contractors at Portland has accomplished the purpose intended, but we would not nor could not adopt this method if we were laying another pipe across the Bay of San Francisco, or across any other water where it was rough or deep; and while we think the joints of the Portland pipe could have been made tight enough by accurate workmanship, still the results obtained by the use of pressure accomplished the same desired end, in that particular case, at much less expense, and in a manner that should be just as permanent."

The occasion of the controversy between the Chief Engineer and the contractors, referred to in the paper, was occasioned, in a word, by the fact that the latter chose what was considered by the former a novel method of making the pipes tight. When the pipe was designed it was never intended to be made tight in any other way than by such close and accurate workmanship in turning as would leave it tight after bending the joints at any time and in any way desired.

* See the *Transactions* of the Institution of Engineers and Shipbuilders in Scotland, Vol. XXXI, p. 207.

Therefore, the proposition to make leaky joints tight by pulling on them after they were laid was only acceptable under stress of compulsion to avoid an impending crisis, as a few weeks of delay at that time meant the postponement for another season of the completion of the entire plant, with its attendant expense for pumping and interest, amounting to more than the contract price of the submerged pipe in controversy. Mr. Schuyler.

FRANKLIN RIFFLE and ALBERT S. RIFFLE, Members Am. Soc. C. E. —The authors would preface their closing remarks with a brief account of a later test than the one described in their paper. This test was made during the night of February 20th, 1895, three months after the completion of the work and two days prior to its acceptance. As the authors were not given an opportunity to be present, they were compelled to avail themselves of information kindly furnished them some days later by one of the assistant engineers who had been detailed by the Chief Engineer to test the pipe line. When the gates were closed, the gauge in the gate-chamber recorded a pressure of 120 lbs. After about six or eight strokes of the hand pump connected with the pipe line, the engineer directed his lantern to the gauge and was much surprised to find that it recorded a pressure of 150 lbs. As his instructions had been not to exceed the working pressure, 140 lbs., the pump was stopped until the pressure receded 10 lbs. It was then found necessary to pump 5 galls. of water into the pipe line to hold the gauge at 140 lbs. for a period of 12 minutes. The apparent leakage was, therefore, less than $\frac{1}{2}$ gall. per minute. The engineer, however, assumed that the gates leaked the same amount as when the previous test was made, viz., $\frac{1}{4}$ gall. per minute. As the pump, also, was in a leaky condition, he was forced to the conclusion that the line was practically tight, and so reported to the Chief Engineer. Messrs. F. and A. S. Riffle.

The authors had hoped the discussion would bring out some important facts relative to the method of casting ball and socket pipe, reference to which was inadvertently omitted in preparing the paper. Both Mr. Kuichling and Mr. Duane emphasized the importance of reinforcing the socket, owing to the danger of fracture arising from tensile strains. In this connection, the fact should not be ignored that the quality of the metal in the bell or socket is sometimes much inferior to that in any other portion of the pipe, owing to the practice of some manufacturers to cast the bell end uppermost. This practice should be condemned, since the saving in cost scarcely cuts a figure in the matter. However conscientious and painstaking a manufacturer may be, impurities will rise to the top and become a portion of the shell. While the presence of slag and sand, and numerous blow-holes adroitly filled with a combination of iron filings, sal ammoniac and flowers of sulphur, concealed from view by the usual preservative, may escape the eye of the inspector, such imperfections are hardly consistent with what is generally understood by a "good gray casting."

Messrs. F. and A. S. Riffle.

While an imperfect casting of this description might pass the usual hydraulic test, such a test would furnish no guarantee that it would successfully withstand great radial strains due to the wedging of the ball in the socket; hence, the importance of having the best metal instead of the poorest in the socket. This could be accomplished by reversing the usual practice of casting, in which case the impurities would rise to the last few inches of the ball, which is subjected to neither radial or longitudinal stresses when in place, and being confined to that portion of the ball which is outside the limit of flexure, the rough surface, due to slag or blow-holes, should such exist after machining, would not come in contact with the lead. While there may be some doubt whether a truly spherical and smoothly finished ball will require a longitudinal pull to secure a water-tight joint, it should, nevertheless, be borne in mind that conditions are always likely to exist when pipes are laid in the bottom of a stream, such as settlement or undermining, which may impose an equal amount of longitudinal strain. In view of these facts, the suggestion of Mr. Kuichling that the socket be reinforced by a band of wrought iron or steel is an excellent one. Mr. Duane's method of reinforcement is immeasurably superior to that used at Portland, for reasons which will appear later on.

The criticism of Mr. Tribus that the exact cost of the work was not given has been satisfactorily answered by Mr. Croes, and the data contained in the paper are sufficient for an engineer to make a reasonably close estimate of the cost of work to be done under similar conditions.

As Messrs. Emery and Gould stated, perfect lathe work is always preferable to imperfect work, and with the requisite amount of care "it is just as easy to turn the joints perfectly true as not to do so." However, the slight inaccuracies noted were not sufficient grounds for rejecting the pipes at the risk of delaying the completion of the water system for a period of one year, not to mention the palpable injustice of such a proceeding to the contractors, who had from the first acted only in good faith, relying solely upon the shop inspector appointed by the Chief Engineer. It was pleasing to note that an engineer of such wide experience and reputation as Mr. Duane had taken the same position. The latter's statement based on experience, that the tightness of flexible joints is "dependent upon their being laid on their final bed under a strong tensile strain" is of great value, since it establishes the fact that, while it may be possible to secure tight flexible joints without this "tensile strain," under certain favorable conditions, such as light pipes and perfectly turned joints, the method of laying the pipes under tension insures absolute success under any and all conditions.

Concerning Mr. Ward's remarks, it should be said that in describing their method of laying submerged pipes the authors gave no thought as to whether the method was original with them or not,

although at the time they prepared the plans for the cradle they had neither seen nor heard of a similar contrivance. Some time afterward, however, their attention was called to an illustration of an inclined plane used in laying a 24½-in. steel riveted pipe, with flexible joints, across the River Maas in Holland. This device differed from the one designed by the authors principally in two respects, viz., there was no provision made for a change in the depth of water, and the slide being an inclined plane, admitted of no deflection at the joints until the pipes reached the bottom, thus necessitating a very long and unwieldy contrivance. Messrs. F. and A. S. Riffle.

Mr. Ward's deductions relative to the static friction of the pipes on the bottom of the trench are incorrect, since no allowance was made for the action of gravity. The 650 lin. ft. of pipes tested to 250 lbs. per square inch were on a descending grade, 190 lin. ft. being on a 12½% grade, and the remaining 460 lin. ft. being on a grade of about 5½ per cent. Mr. Ward assumed that the total force of 250 lbs. per square inch was exerted to overcome the static friction of the pipes on their bed, which was not the case. While it was quite evident that a large percentage of the applied force was necessary to start the lead in the large end of the reducer, the exact amount could only be a matter of conjecture. A more reliable frictional coefficient might be obtained from the experimental test of the first eight pipes laid, six of which lay level in the trench previous to its excavation below the water-line, the last two lying on a grade of 12½ per cent. During this test the joints gradually tightened in succession from the free end toward the reducer, the leakage at the last flexible joint diminishing quite perceptibly at a pressure of 35 lbs., and the joint becoming absolutely tight at a pressure of 45 lbs. per square inch. The former, then, would represent the force required to overcome the static friction of the pipes. The coefficient of friction was, therefore, about 0.27.

The statement that "the advantages in favor of the long pipes are obvious," concerning which Mr. Duane raised some questions, was intended to refer more particularly to the reduced cost of construction, as well as to the fact that the reduced number of joints, each liable to either vertical or horizontal deflection, or both, would offer less resistance to the flow of water. A long pipe will bridge over the inequalities which exist necessarily in a dredged trench. These soon become filled up by the action of the current. Such was the case with this particular line, portions of which were half buried at the time of completion. For this reason there was not the same necessity for using short lengths as in the case of the "irregular rocky bottom" of East River in the vicinity of Blackwell's Island. The use of short joints for facilitating repairs would, however, be quite advantageous.

Mr. Duane's questions are answered as follows :

First.—The lead was poured and calked in two separate operations, as described by Mr. Fanning.

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Second.—The rib, which served as a lead stop, answered the purpose admirably, making the use of yarn unnecessary.

Third.—The pourings were made from a kettle, suspended over the joint by the derrick used for handling the pipes, and having an orifice in the bottom, which could be quickly opened or closed by means of a vertical screw. The lead should be run at one pouring, and calking was unnecessary; but as the work was done under the supervision of the Chief Engineer, the authors had no option in the matter.

The answer to Mr. Dunham's remarks is that the cradle was employed for the purpose of supporting the pipes until they reached the bottom of the trench, thereby avoiding excessive strains on the sockets, which would have occurred had the pipes been merely suspended from the pipe-laying barge. Owing to the great weights of the pipes the latter method would not only have resulted in straining the sockets at the risk of cracking them, but would also have had the effect of wedging the shoulders of the ball ends tightly against the collars, so that the joints would have become inflexible, and many would, no doubt, have refused to accommodate themselves to the bottom of the trench.

The following were the probable reasons of the Chief Engineer for deciding upon the use of flexible joints:

First.—The pipes could be laid without obstructing navigation.

Second.—They would readily conform to irregularities in the bottom of the trench.

Third.—In the event of possible shifting of the channel during freshets there would be far less danger of leakage or rupture. As this is a portion of the main-pipe line which supplies the city of Portland with water, the Chief Engineer was expected to take every reasonable precaution against accidents which would tend to shut off the water supply.

Mr. Dunham's query, "Why was the integrity of an important line left dependent upon the threads of 1-in. iron bolts and nuts which may be exposed in the river bottom to corrosive substances," opens up an interesting question relative to this design of the joint, and suggests radical defects which were fully confirmed by experience. A collar, if used at all, should not be cast in sections. A glance at the sketch of this joint (see Fig. 1, page 258), will plainly show the weakness of the collar at the connections, where two thin lugs of cast-iron are subjected to great bending moments, the result of radial stresses in the collar. It is apparent that these lugs are wholly inadequate to withstand the stresses that must necessarily come upon them when the line is subjected to tension. As a matter of fact, some of the lugs were broken by calking alone, others by bolting (although the greatest care was exercised to avoid undue strains), while many were broken during testing, the fractures always occurring at the connections. Whenever a fracture occurred while testing, a muffled sound could be heard on the barges accompanied by a perceptible movement of the pipe. In the gate chamber the reports due to the breaking of the lugs were greatly in-

tensified, and on several occasions had the effect of speedily expelling the occupants. Messrs. F. and A. S. Riffle.

The proper endwise strain or pull upon the submerged line could not be continued after the connection was made with the larger pipe at the completed end. This was not essential, since the joints were pulled tight before the connection was made.

In reply to Mr. DeCourcy, it is to be said that the Chief Inspector of the Water Committee predicted that it would be an absolute impossibility to make the joints tight without the use of hemp packing, and that in deference to his recommendation the Chief Engineer authorized the contractors to use a packing of some sort before pouring the lead. They, however, being firmly convinced of their ability to make the joints tight with lead alone, and not wishing to give an opportunity for raising the question that the joints would remain tight only until the packing decayed, declined to take advantage of this concession. The result has clearly demonstrated the wisdom of their course.

While it was unnecessary to exceed the normal pressure so extremely, the fact should not be lost sight of, that the contractors were compelled to make the joints, not only practically, but absolutely, tight, or run the risk of not having the work accepted upon its completion.

Mr. Schuyler's eminent services as Consulting Engineer of the Portland Water Works, particularly as designer and engineer of the four large distributing reservoirs, certainly justifies the very modest reference to himself. Passing over the historic portion of the discussion, which is undoubtedly correct, the authors desire to correct an error in reference to the curvature of the cradle which Mr. Schuyler describes as a "true 10° curve." The degree of curvature was about 61½°, while the axial deflection of the pipe was 10°.

Mr. Schuyler's position in refusing to admit the possibility of compression in the lead, due to the increased weight of the pipe when raised, owing to the back lead stop, is untenable, inasmuch as this small run, like all the rest of the metal, was covered with a coat of asphaltum paint. That this coating would sustain such a weight, especially after being heated to a liquid condition by the hot lead, is hardly probable. It is, then, safe to assume that it offered but little resistance to compression or abrasion during rotation. When pipe-laying began from the cradle, this coating was removed from the back lead stop, as well as from the interior of the bell covered by the lead. In stating that "the leakage at the top of the pipes was observed before as well as after the pipes had been lowered," he has been misinformed. As these experiments were conducted solely for the benefit of the Chief Engineer, the work was done to suit his inspector, who insisted that each length should be raised and then lowered, as laid. Only the last of the eight lengths was allowed to remain as calked, at the special request of the contractors. A test of these eight lengths was then made, the leakage in the last joint being very small, but not

Messrs. F. and A. S. Riffle.

confined to any particular portion of the run. Mr. Schuyler advanced at the time the same opinion expressed in his discussion, viz., that the leakage arose from "sponginess in the lead due to confined air in the lead space," and recommended drilling a hole in the uppermost portion of the bell, to permit the escape of air. The contractors could not at the time, neither do the authors now, in the light of subsequent events, accept the suggestions offered as a conclusive solution of the difficulty.

The pouring vent was at all times sufficiently large to permit the free escape of air, and an air space in the extreme upper part of the bell was only possible when the pipes were not sufficiently inclined to permit a free escape. In laying from the cradle, the great angle of inclination precluded any possibility of confined air. The position taken by the contractors in this matter was fully confirmed in an examination of the lead removed from the two broken sections of pipe on the west bank, both joints of which were poured while the pipe was in a horizontal position. The lead presented a perfectly homogeneous appearance throughout, with no sign of air obstruction, even in the topmost portion. The effect of the calking did not extend noticeably beyond $1\frac{1}{2}$ ins. in depth, which is usual for lead calking.

Mr. Schuyler's description of the double line of 16-in. pipe across San Francisco Bay for the Spring Valley Water Company is very interesting, but would be decidedly more so and of greater value had he pursued his inquiries further and obtained some definite and accurate data concerning the tightness of the line after completion. His reference to the excellent result of the shop test deserves notice. A description of the method employed in conducting that test would have been of great interest, especially the means adopted to prevent calking by hydraulic pressure. His silence upon that point, coupled with the statement that the pipe was revolved during test, carries with it the suspicion that the test was identically the same as that adopted by the authors.

He states that "at Portland a diver was continually employed calking joints under water." This statement is incorrect, as may be seen by a careful perusal of the paper, which says that "little calking under water was necessary, however, the joints being practically tight from first to last." The amount of calking under water in the whole line would not exceed two or three hours of actual labor.

In closing his discussion, Mr. Schuyler states that it was never intended to make the pipe line tight "in any other way than by such close and accurate workmanship in turning as would leave it tight after bending the joints at any time and in any way desired." He must have known, in virtue of his position as Consulting Engineer, that the specifications were decidedly lacking in reference to the points at issue. That the method finally adopted by the contractors to secure good results was not novel, as stated by Mr. Schuyler, has been fully established by this discussion.

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748.

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SPECIFICATIONS FOR STRUCTURAL STEEL.

By H. H. CAMPBELL, M. Am. Soc. C. E.

READ APRIL 3D, 1895.

WITH DISCUSSION.

In the consideration of a specification for structural steel there are three fundamental subdivisions.

First.—The method of manufacture.

Second.—The chemical composition.

Third.—The physical properties.

Some engineers are content with testing the finished material, claiming that it is the province of the manufacturer to obtain the required properties by any method he may choose.

Others prescribe a chemical formula or set maxima for certain elements and let the maker do as he will in reaching the result. Still others go to the root of the matter and specify in just what kind of a furnace the steel shall be made, just how that furnace shall be lined, just what stock shall be charged, and just what size ingots shall be cast.

The following pages will endeavor to show that the mode of manufacture and the composition of the metal should be laid down in the

contract, but that some of the latest specifications have carried the requirements in this direction as far as reason will allow, while there is room for great improvement in the determination of the physical properties.

I.—The Method of Manufacture.

It is a current impression among many engineers that the method by which steel is made can be found by making a chemical analysis. Let it be stated, therefore, that although certain experiments indicate a difference between Bessemer and open-hearth metal in the character of the occluded gases, this system of analysis is never resorted to in practice and no provision is made for it in laboratories. Moreover, it is doubtful if any expert would risk his reputation by asserting positively from any such evidence that a certain steel was made by either one or the other process. Aside from this occult and unused method it is certain that the ordinary systems of testing fail entirely to distinguish the product of the open-hearth furnace from that of the Bessemer converter. Notwithstanding this fact there is good testimony to show that the product of the converter is an inferior metal which gives way in a treacherous manner under shock. It is granted that in a strict sense there is no such thing as treachery or mystery, but these are convenient terms to cover an undiscovered law.

The evidence concerning the unreliability of Bessemer steel is made up, for the most part, of scattered individual opinions, many of which have been made on insufficient evidence, but they are too numerous to be entirely ignored and they are fortified by the carefully considered statements of men whose words are weighed and who are absolutely disinterested in their decisions. Thus Mr. A. E. Hunt, whose long experience as the chief of the Pittsburgh Testing Laboratory gives much force to his opinion, writes as follows :* "Numerous cases have come under our observation of angles and plates which broke off short in punching, but although makers of Bessemer steel claim that this is just as likely to occur in open-hearth metal, we have as yet never seen an instance of failure of this kind in open-hearth steel."

Mr. Hunt also quotes* from a paper by Mr. Wailes before the British Association to the effect that "these mysterious failures occur in steel of one class, viz., soft steel made by the Bessemer process." We have

* See the *Journal* of the Iron and Steel Institute, Vol. II, 1890, p. 316.

also the testimony of Mr. W. H. White, Director of Naval Construction, Royal Navy :* "With converter steel, riveted samples have given less average strength, greater variations in strength, and much more irregularity in modes of fracture than similar samples of open-hearth steel. The basic open-hearth metal has proven to be as good as that made on the acid open hearth, and after full investigation it will be used by the Admiralty in ship plates and boiler tubes on an equal footing."

It is acknowledged that the case is not yet closed, but until these statements are controverted by direct and positive evidence, the only safe way for the engineer is to prescribe that only open-hearth metal shall be used in all structures like railroad bridges, where the metal is under constant shock and where life and death are in the balance. And it should be emphasized that if this provision is incorporated, a careful watch should be kept for fraud, as there is no way in which a substitute can be detected. The objections to Bessemer steel are many times emphasized in the product of the basic converter, for at the end of the operation there is often a very considerable percentage of phosphorus that passes back from slag to metal, and which is not always uniformly distributed. This fact utterly condemns it for the best of work. This objection does not hold true with respect to the basic lined open-hearth furnace, for while a basic converter absolutely requires a high content of phosphorus in the iron and a correspondingly impure slag, and while the reaction during recarbonization in basic Bessemer practice is almost always violent, the basic-lined open hearth does not require a very impure iron, the slag is not necessarily impure, the reaction with the recarbonizer is not violent, and the amount of rephosphorization is almost inappreciable.

A very common argument against basic steel is that good steel cannot be made from bad stock. Unfortunately this statement is sustained by many so-called practical men who have no knowledge of any process which was not tested and proven in the days of their infancy. To a certain extent the thesis was once true, but from a broader point of view it has always been wrong. The finest acid steels, both open hearth and crucible, have long been made from washed pig iron, puddled iron or charcoal blooms, all produced by the application of a basic process to a more or less phosphoritic iron. If, then, the best steels are made by remelting the product of a basic hearth, it is not inherently im-

* See the *Journal* of the Iron and Steel Institute, Vol. I, 1892, p. 135.

possible that the product of a basic hearth may be cast directly into good steel. The basic open-hearth furnace has come to stay. It can not make common steel any cheaper than the acid process, but it can produce more economically a tough, ductile, pure metal which is fast finding its way into general use.

The careful engineer may conscientiously refuse to employ the new material, but let him acknowledge that his decision is an honest conservatism, and let him not lay down metallurgical laws concerning that which is outside his domain. The steel-makers of this country stand ready to supply either acid or basic open-hearth metal of any desired quality, but they ask of the engineer that the terms of the contract as to the method of manufacture be enforced, in order that a maker who bids on a certain lot of low-phosphorus acid steel may not be underbid by a competitor who trusts that he can obtain a concession and make it on a basic hearth. There is less cause for watchfulness in the case of steel containing over 0.08% of phosphorus, since such metal should not be used in structures exposed to shock, and since the basic hearth possesses little, if any, economy over the acid furnace in the manufacture of such material.

II.—The Chemical Composition.

It is generally recognized as both undesirable and impracticable to specify the complete formula for a steel of a given strength and ductility. Within certain limits the manufacturer should be permitted to use whatever he thinks will best meet the requirements. A too rigorous adherence to some good formula would effectually prevent the discovery of better alloys. Moreover it is plain that if steel is made strictly in accordance with the prescription, the responsibility of failure and loss must rest with the engineer and not with the maker. These propositions are so axiomatic that it may seem superfluous to recite them, but as a matter of fact it is a very common occurrence for the steel-maker to receive an order where almost every element is specified, together with an ultimate strength which is impossible under the conditions. Granting, therefore, as self-evident that a complete formula must not be prescribed, there remains to be considered how far it is advisable to define the chemical content of the separate elements.

Carbon.—In all the structural steels used to-day, a variation in strength is produced either in whole or in part by a variation in the

carbon content, and this metalloid is so competent to perform its functions, that a high metallurgical authority has declared that pure steel is pure iron plus pure carbon, and that all other elements are impurities. Leaving aside this ultra and widely disputed statement, there remains the fact that it is the main reliance of the steel-maker and that probably no other element can confer a given increase in strength with as little diminution in ductility and as little increase in brittleness under shock. It is, therefore, absurd to place any limit to the carbon content in a steel of a given ultimate strength, since a high percentage necessarily denotes a correspondingly low content of other metalloids.

Silicon.—The contradictory testimony concerning the effect of silicon on steel has been well summarized by Mr. Howe in his "Metallurgy of Steel," where many examples are recorded of exceptional steels with abnormal contents of silicon, and where the theories advanced by different writers are fully discussed. He finds no proof that silicon has any bad effect upon the ductility or toughness of steel, and argues that the bad quality of certain specimens is not necessarily due to the silicon content, but to other unknown conditions. A Bessemer steel with high silicon is sometimes produced by hot blowing, but it will be entirely wrong to compare such metal with the common product and ascribe all differences to the chemical formula rather than to the circumstances which created that formula.

Further experiments by Mr. Hadfield* show that steel may contain as much as 3.4% of silicon, with a tensile strength of 106 000 lbs. per square inch, and still register an elongation of 11.1% in a length of 2 ins. These results are of the highest value in showing that silicon cannot be classed among the highly injurious elements, for in similar proportion phosphorus and sulphur would be out of the question, manganese would give a worthless metal, and carbon would change the bar to pig iron. It will therefore be only reasonable to suppose that small quantities cannot exert a very deleterious influence.

It is well known that many continental works have habitually made their rails with from .30 to .60% of silicon and that all requirements of strength and ductility have been met. In fact, the author was told by the manager of one of the French establishments that the only way in which he was able to fill one contract, with particularly severe

*See the *Journal* of the Iron and Steel Institute, Vol. II, 1889.

specifications, was by making the steel from .30 to .40% in silicon, since a less proportion would not stand the drop tests. It is not necessary to question whether this conclusion was warranted or not; it is enough to know that the steel was of the best quality, whether on account of the silicon or in spite of it.

The fact that silicon may be allowed in rails has been acknowledged by Mr. Sandberg, who writes as follows:* "Silicon up to .30%, with carbon .30 to .40%, does not harden steel or make it brittle, and diminishes its strength in such small degree as not to imperil the safety of the rail." Exceptional cases have been recorded of soft steels with high silicon, like the very tough rail mentioned by Mr. Snelus,† with carbon below .10%, and silicon .83 per cent. It must be considered, however, that although this might have been very tough for a rail, it does not follow that it was very tough for soft steel, but it is quite certain that it could not have been bad or brittle.

With the knowledge possessed concerning the relative effect of impurities upon hard and soft steels, the assumption would almost be justified that low-carbon metal might be allowed to contain a larger percentage of silicon than higher steel. There is no need, however, of such an admission, for structural steels do not usually contain over .10% of silicon, while usually it is below .05 per cent.

Sulphur.—The prominent characteristic of sulphur is its power to make the steel crack and tear in hot working, and this affects the manufacturer rather than the engineer. The influence of this metalloid upon the cold properties has not been accurately determined, but it is quite certain that it is not very important. In common practice the content varies from .01 to .10%, and within these limits it seems to have no appreciable influence upon the elastic ratio, the elongation, or the reduction of area, and there is no evidence to indicate that it causes brittleness under shock. It follows, therefore, that no stringent specifications are necessary regarding this element as far as plates, angles and other shapes are concerned. In rivets, however, the case is different, for here the metal must be heated to a high temperature, and it is quite certain that sulphur will tend to create a coarse crystallization in the steel and thereby injure the strength and toughness of the joint.

*See the *Proceedings* of the Institution of Mechanical Engineers, 1890, p. 301.

†See the *Journal* of the Iron and Steel Institute, Vol. II, 1882, p. 583.

Copper.—The remarks which have just been made about sulphur are also applicable to copper. It injures the rolling quality of the steel, but has no appreciable effect either upon the ultimate strength or ductility, and hence there is no occasion for the engineer to consider it, except in the case of rivets where an excessive content may cause the metal to be red-short. The effect of copper, however, unit for unit, is only a fraction of that which sulphur exercises. Hundreds of thousands of tons of excellent steel have been made containing over 0.5%, and millions of tons containing over 0.25 per cent.

The Pennsylvania Steel Works has probably had a far wider experience in the use of cupriferous metal for all grades of steel, both low and high, than any other works in the world, and we have yet to learn that it affects either the strength or the ductility of the finished material. It is not easy to make a comparison between high and low copper steels, for at works using such material it is customary to keep a fairly constant percentage in the mixture rather than to vary between wide limits. A few heats are shown in Table No. 1, and although the list is not as long as might be desired, it should be considered that the heats were all made within a short period in the same Bessemer, and were all rolled in the same mill :

TABLE No. 1.

COMPARATIVE PHYSICAL PROPERTIES OF LOW AND HIGH COPPER-STEEL ANGLES.

Thickness in inches.	Copper. Per cent.	Number of heats.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Elastic ratio.
$\frac{5}{16}$	.10	11	61 376	44 152	27 52	56.30	71.9
	.35	17	60 283	43 841	27.88	59.01	72.7
$\frac{3}{8}$	.10	10	58 965	42 218	28.85	55.50	71.6
	.35	11	59 630	43 478	29.02	57.86	72.9

This limited investigation cannot prove conclusively that copper is beneficial, but it does indicate that this element has been unjustly

maligned. In view of the good quality of angles containing .35% of this impurity, it seems a trifle absurd to find a specification that sets the maximum at any such figure as .05 per cent. It must be kept in mind by engineers, that there is no way of eliminating copper in either an acid or basic furnace, and as a large percentage of the iron and the steel scrap east of the Allegheny Mountains contains a considerable proportion, the eastern manufacturer can avoid it only by buying selected material at a considerably increased cost.

Manganese.—Spiegel iron or ferro-manganese is added to a heat of steel at the time of tapping, in order that it may seize the oxygen which is dissolved in the bath and transfer it to the slag as oxide of manganese; but this reaction is not perfect, and there is reason to believe that all common steels contain a certain percentage of oxygen. It is a question whether this does any great harm, for it seems probable that some manganese would be necessary to make the steel work well, even if no oxygen were present. Steel low in phosphorus and sulphur requires less manganese than impure metal, although it is difficult to see why there should be less oxygen to counteract, and this indicates that the function of the manganese is to prevent the coarse crystallization which the impurities would otherwise induce. Besides conferring the quality of hot ductility, manganese also raises the critical temperature to which it is safe to heat the steel, for just as it resists the separation of the crystals in cooling from a liquid state, so it opposes their formation when a high thermal altitude augments the molecular mobility.

These two manifestations of the same general force render manganese one of the most valuable and essential factors in the making of steel, although there is no doubt that it has been used too freely in some cases. Years ago, some of the rail-makers of the country looked upon it as a panacea for all bad practices in the Bessemer department and rolling mill, and steel often contained from 1.25 to 2.00% of manganese, but it was soon discovered that such rails were brittle under shock, so that the permissible maximum has been gradually lowered, and the standard product of the present day contains from .60 to 1.00 per cent. In higher steels the same lesson has been learned, but in this case the necessity of a low content is far more marked, since a percentage which is perfectly harmless in unhardened steel will cause cracking if the metal be quenched in water. For this reason it is advisable to

reduce the proportion of this element in hard steel to the lowest possible point.

In structural metal there is no quenching to be done and the limit need not be placed too low, for the decrease in toughness due to an increase in the content of manganese is less marked than often supposed, as will be shown by Table No. 2. This is made by grouping together heats of the same character and about the same tensile strength, and separating them into two classes according to the manganese content. No arbitrary line is drawn between a high and low percentage, but each group is divided so that the number is as nearly equal as possible on each side. An unequal number is due solely to the fact that several heats may have exactly the same content, and these must all go either on one or the other side of the line.

It will be evident that there is no marked difference between the steels of high and low manganese, and the results of the eight different groups are so uniform in their testimony that the work of chance must be almost absent. These records of ductility, however, do not take into account the very important quality of resistance to shock. It has always been a problem to devise some way of applying a satisfactory test in this direction, but the method is yet to be found. A few crude experiments which the author performed on steel of high manganese to see how it would act under shock are given in Table No. 3. The bar was struck while in tension with a copper hammer, each blow being powerful enough to have bent the bar permanently, if it had not been continually straightened by the action of the machine. One of the effects of this hammering is to momentarily loosen the bar in the grips and make a sudden jar upon the piece. This action, coupled with the stress upon the outside fibers and the direct vibration, make the test quite exhaustive, although from the difficulty of measuring the force of impact it can hardly be called practical. Some of the bars were not struck until "failure," or until the maximum stress had been reached. This was on account of the trouble from slipping or jumping, above noted, which followed the hammering at earlier periods, and it was taken for granted that, if a bar would break at all from shock, the fracture would be likely to occur about the time when the piece was under destructive tension. It will be evident that the hammering did not in any case determine the time of breakage, for each piece gave as good an elongation and reduction of area as a part of the same rod which was pulled in the usual manner.

TABLE No. 2.

COMPARATIVE PHYSICAL PROPERTIES OF OPEN-HEARTH STEEL WITH DIFFERENT CONTENTS OF MANGANESE. MADE BY THE PENNSYLVANIA STEEL COMPANY.

Group.	Kind of steel.	Limits of ultimate strength in group. Pounds per square inch.	Phosphorus. Per cent.	Relative manganese.	Number of heats.	Manganese. Per cent.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Elastic ratio.	Shape of test.
I.....	Acid..	55 000 to 60 000	.08	Low	7	.30	57 922	38 692	29.91	59.02	66.8	¾″ diam.
				High.....	6	.37	58 881	38 598	28.08	57.07	65.6	
II.....	Basic..	55 000 to 63 000	.03	Low	11	.44	58 005	38 547	30.16	60.21	66.5	2″ × ⅜″
				High.....	11	.57	59 563	40 133	30.36	58.55	67.4	
III.....	Acid...	60 000 to 65 000	.08	Low	16	.35	62 180	41 308	28.00	50.89	66.4	¾″ diam.
				High.....	14	.51	62 605	41 169	27.65	54.66	65.8	
IV.....	Acid...	65 000 to 70 000	.08	Low	26	.51	67 421	43 923	25.96	51.29	65.1	¾″ diam.
				High.....	32	.78	68 192	45 854	25.82	51.50	67.2	
V.	Acid...	70 000 to 75 000	.08	Low	18	.60	72 353	46 836	24.23	47.79	64.7	¾″ diam.
				High.....	25	.91	72 115	48 359	24.63	47.73	67.1	
VI.....	Acid...	75 000 to 80 000	.08	Low.	11	.65	77 520	49 411	22.34	44.42	63.7	¾″ diam.
				High.....	11	.84	78 083	50 226	23.63	48.49	64.3	
VII.....	Acid...	80 000 to 85 000	.08	Low	9	.68	81 747	51 219	20.63	41.04	62.7	¾″ diam.
				High.....	9	.82	81 860	52 231	22.67	47.75	63.8	
VIII.....	Acid ..	85 000 to 90 000	.08	Low	5	.75	86 460	54 517	20.41	40.56	63.1	¾″ diam.
				High.....	5	.83	88 034	55 409	20.66	41.92	62.9	

TABLE No. 3.

RESISTANCE TO SHOCK OF STEEL CONTAINING ABOUT 1.00 PER CENT. OF MANGANESE. MADE BY THE PENNSYLVANIA STEEL COMPANY.

(All tests ¾-in. rolled rounds.)

Heat number.	Manganese. Per cent.	Conditions under which test was made.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
6960..	1.00	Average of two tests; pulled quietly	71 040	47 055	25.87	55.05
		Average of two; hammered from start to finish	70 770	46 380	26.12	61.40
6961..	1.03	Average of two tests; pulled quietly	72 175	48 075	27.00	54.98
		Average of two; hammered from start to finish	71 120	47 330	26.00	59 20
6962..	0.94	Average of two tests; pulled quietly	74 020	48 165	25.62	52.60
		Average of two; hammered from start to finish	74 490	48 340	23.50	55.70
6963..	1.13	One bar; pulled quietly	81 070	52 880	22.50	43.60
		One bar; hammered from elastic limit to fracture	80 460	52 760	23.50	48.30
		One bar; hammered from failure to fracture.	78 050	51 800	19.25	55.30
		One bar; began hammering at 72 000 lbs., and moved scale weight back as the bar weakened	69 040	52 760	21.00	47.80
6981..	0.82	One bar; pulled quietly	67 340	46 030	28.12	55.00
		One bar; hammered from failure to fracture.	65 940	44 430	28.00	57.90
6982..	0.91	One bar; pulled quietly	66 700	46 310	26.00	55.93
		One bar; hammered from failure to fracture.	67 240	46 090	31.25	55.60
6983..	1.03	One bar; pulled quietly	69 700	47 650	26.00	51.70
		One bar; hammered from failure to fracture.	70 080	46 360	27.12	53.70

Phosphorus.—Of all the elements that are commonly found in steel, phosphorus stands pre-eminent as the most undesirable. It is objectionable in the rolling mill, for it tends to produce coarse crystallization, and, hence, lowers the temperature to which it is safe to heat the steel. For this reason phosphoritic metal should be finished at a lower temperature than pure steel, in order to prevent the formation of a crystalline structure during the cooling. Aside from these considerations its influence is not felt in a marked degree in the rolling mill, for it has no disastrous effect upon the toughness of red-short metal when the content does not exceed .15 per cent. The action of phosphorus upon the finished material may not be dismissed in so few

words. Mr. Howe * has gathered together the observations of different investigators, and the evidence seems to prove that the tensile strength is increased by each increment of phosphorus up to a content of .12%, but that beyond this point the metal is weakened. Whether this last observation be correct or not is of little practical importance, for it would be criminal to use a metal for structural purposes that contained an average of .12% phosphorus. Below this point the author is absolutely certain that phosphorus strengthens low steels, both acid and basic, and he believes that it has about the same power in this direction as carbon, unit for unit. The same certainty does not pertain to any other effect of this metalloid.

Mr. Howe has ably discussed the whole matter,* and quotations are herewith made from his "Metallurgy of Steel," and condensed in the form of a summary.

First.—The effect of phosphorus on the elastic ratio, as on elongation and contraction, is very capricious.

Second.—Phosphoric steels are liable to break under very high tensile stress if suddenly or vibratorily applied.

Third.—Phosphorus diminishes the ductility of steel under a gradually applied load, as measured by its elongation, contraction and elastic ratio, when ruptured in an ordinary testing machine; but it diminishes its toughness under shock to a still greater degree, and this it is that unfits phosphoric steels for most purposes.

Fourth.—The effect of phosphorus on static ductility appears to be very capricious, for we find many cases of highly phosphoric steel which show excellent elongation, contraction, and even fair elastic ratio, while side by side with them are others produced under apparently identical conditions, but statically brittle.

Fifth.—If any relation between composition and physical properties is established by experience, it is that of phosphorus in making steel brittle under shock; and it appears reasonably certain, though exact data sufficing to demonstrate it are not at hand, that phosphoric steels are liable to be very brittle under shock, even though they may be tolerably ductile statically. The effects of phosphorus on shock-resisting power, though probably more constant than its effects on static ductility, are still decidedly capricious.

The slight effect of phosphorus upon static ductility will be shown

* The Metallurgy of Steel, p. 67 *et seq.*

by Table No. 4, which is constructed by comparing the acid open-hearth angles in Table No. 11, which are of the same ultimate strength and of the same thickness, but contain different percentages of phosphorus.

TABLE No. 4.

Comparative Physical Properties of Low-Phosphorus and High-Phosphorus Steels.

Comparison of the acid open-hearth angles given in Table No. 11, which are of the same ultimate strength and of the same thickness, but with different contents of phosphorus.

Limits of ultimate strength. Pounds per square inch.	Number of group.	Thickness of angle. Inches.	Phosphorus. Per cent.	Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch.	Average elastic ratio. Per cent.	Average elongation in 8 ins. Per cent.	Average reduction of area. Per cent.
56 000 to 64 000..	I	$\frac{5}{16}$ to $\frac{3}{8}$	0.05 to 0.07	60 443	40 929	67.72	28.66	58.52
			0.07 to 0.10	60 064	41 143	68.50	28.82	58.35
	II	$\frac{7}{16}$ to $\frac{1}{2}$	0.05 to 0.07	61 173	40 164	65.66	28.72	55.73
			0.07 to 0.10	60 583	40 170	66.30	29.05	56.30
	III	$\frac{9}{16}$ to $\frac{5}{8}$	0.05 to 0.07	61 318	39 548	64.50	28.31	52.92
			0.07 to 0.10	61 049	39 656	64.96	28.98	54.81
	IV	$\frac{11}{16}$ to $\frac{3}{4}$	0.05 to 0.07	60 609	38 559	63.63	28.62	50.09
			0.07 to 0.10	59 763	38 338	64.15	29.60	55.33
64 000 to 72 000..	V	$\frac{5}{16}$ to $\frac{3}{8}$	0.05 to 0.07	66 216	43 800	66.15	27.60	54.13
			0.07 to 0.10	66 369	44 480	67.02	27.13	55.64
	VI	$\frac{7}{16}$ to $\frac{1}{2}$	0.05 to 0.07	65 580	42 540	64.87	27.92	54.30
			0.07 to 0.10	65 856	42 846	65.06	27.42	53.15

Analyzing this record, it will be found that the higher phosphorus gives a higher elastic ratio in all six groups. The difference, however, is only a fraction of 1% in each case, so that it is of little practical importance. The higher phosphorus gives a better elongation in all four groups of the softer steel, and a less elongation in the harder steel. A general conclusion to this effect would not be justified, but it can certainly be stated that a moderate increase in phosphorus does not materially reduce the elongation of soft steel. The higher phosphorus gives a better reduction of an area in four groups, and a worse reduction in two groups. Here, again, it may be confidently concluded that a moderate increase in phosphorus does not seriously decrease the reduction of area.

It is the difference between static and shock ductility which makes phosphoric steel so dangerous. In the ordinary testing machine there is no important difference between a pure steel containing less than .04% of phosphorus, and a common steel with .08%, so that the average engineer concludes that the metals are the same. Not only constructive engineers, but men calling themselves metallurgists have staked and have lost their reputations in promoting new processes designed to make good finished material out of steel containing high phosphorus. Many a time the metallurgical world has been stirred by some new discovery, whereby such metal was induced to show a high ductility in the testing machine, and each time the new process has passed away "unwept, unhonored and unsung," as it was rediscovered and rediscovered that static and shock ductility were totally different properties, and that the high phosphorus metal gave lamentable failures as soon as it went beyond the watchful care of its parents and its nurses. It is true that numerous cases can be cited of rails, plates, etc., containing from .10 to .35% of phosphorus, which have withstood a long lifetime of wear and adversity, but in the general use of such metal there has been such a large percentage of mysterious breakages, that it seems quite well proven that the phosphorus and the mystery are the same.

Much information on the effect of phosphorus may be gathered from a study of high steels. A very severe trial is put upon a cold chisel or similar tool in the resisting of the continued shock on the sharpened edge, and it is undeniable that each increment of phosphorus has its effect in rendering such a tool brittle. It is true that in this case the steel is quenched, and also that it contains a considerable proportion of carbon, but there is no evidence to show that the effect of phosphorus is different when the carbon is high, even though it be true that it is more marked. Neither is there any reason to suppose that the quenching changes its nature, for experiments with high phosphorus steel of low carbon indicate that sudden cooling would rather counteract the influence of phosphorus than enhance it, since it tends to prevent the formation of coarse crystals. It would seem, therefore, that the regularly increasing banefulness of phosphorus as the carbon is raised does not portray any change in nature, but that, although the effect of the metalloid in lower steels is obscured, its character is the same. No line can be drawn that can be called the limit of safety, since no

practical test has ever been devised which completely represents the effect of incessant tremor. For common structural material the critical content has been placed by general consent at .10%, but this is altogether too high for railroad bridge work. All that can be said is, that safety increases as phosphorus decreases, and the engineer may calculate just how much he is willing to pay for greater protection from accident.

The Physical Properties.

One of the fundamental difficulties in writing specifications is to decide the nature of the test piece to be required, inasmuch as the strength and ductility will be very different in plates of different thickness, and the properties of these will differ from the properties of angles or rounds which may be rolled from the same steel. From one point of view, each piece of metal throughout a bridge should be of exactly the same strength per unit of section, without regard to its thickness, but in taking this as a basis a serious trouble is encountered. Suppose, for instance, that a metal is required running between 56 000 and 64 000 lbs. per square inch, and a charge is made which in $\frac{3}{4}$-in. plate gives 57 000 lbs. If this steel be rolled into $\frac{7}{8}$-in. angles or into 2-in. rounds, it is quite possible that these will run below the allowable minimum. On the other hand, if the steel gives 62 000 lbs. in a preliminary test, the larger sections will give proper results, while $\frac{1}{4}$-in. plate will be too high in ultimate strength.

Where a structure is to be made of large quantities of very large or very small sections, it is well to specify that the test shall be made on the special thickness needed; but in ordinary cases, it seems absurd to the practical mind that a heat of steel can be perfectly suitable for one size and unsuitable for another. It would be very expensive for manufacturers to fill contracts were it not that inspectors recognize the situation and make tests from the usual sizes, with a full knowledge that thicker and thinner members will give different results. Provisions to cover this point should be incorporated in contracts, and a certain definite allowance be made, so that manufacturers would be obliged to put sufficient work on large members to render them of proper structure, and would at the same time be prevented from finishing thin pieces at too low a temperature. There is often a confusion of terms in considering the effect of work, as represented by a

large percentage of reduction from the ingot, and the effect of finishing at a low temperature. This is found most often in the case of plates, for it has been quite a general practice to roll these direct from the ingot in one heat. In order that a piece shall be finished hot enough under this practice, there has been a standing temptation to use a thin ingot; but, on the other hand, it has been almost universally shown that the best results are obtained when a large amount of work is put upon it in the rolling.

The truth of this last statement was disputed by Mr. Riley,* but it can be shown that his conclusions are not in accord with his premises, and that the best plates were those that received the most work. It will be evident, however, that when a heavy ingot is rolled down to a thin plate in one operation, there will be an enormous strain on the machinery, and probably a cold-finished piece. The effect of this cold finish is very irregular, for the edges and ends are most seriously affected, and the plate is in a bad physical condition. To avoid, on the one hand the objectionable cold finish, and to give, on the other, the advantage of sufficient work, the practice has been gaining ground of rolling a large ingot into a slab, which is proportioned to the plate to be made. By this method all thicknesses may be finished at about the same temperature, without respect to the total amount of work put upon the ingot.

It is a well-known fact that a mass of steel is never absolutely homogeneous owing to certain liquation phenomena known as segregation, and, as it is reasonable to suppose that this action will take place to a greater extent in a large mass of metal than in a small one, it is usually assumed that plates which have been rolled from ingots of large size will show greater variations than those from more usual sections. Paradoxical as it may appear, this is not always true, for in the preliminary "roughing down," or slabbing, of the ingot, the top, which is the most segregated portion, is cut off as scrap. The upper third of the ingot will even then show some segregation in the interior, but Table No. 5 will show that it is of little practical importance.

* See the *Journal* of the Iron and Steel Institute, Vol. I, 1887.

TABLE No. 5.

COMPOSITION OF METAL TAKEN AT DIFFERENT DEPTHS IN OPEN-HEARTH SLABS, ROLLED FROM 32 × 38-IN. INGOTS, MADE BY THE PENNSYLVANIA STEEL COMPANY.

Note : Carbon was determined by color, and is therefore inaccurate.

Number of heat.	Part of ingot.	Size of slab, in inches.	Depth at which drillings were taken, in inches.	Composition. Per Cent.			
				C.	P.	S.	Mn.
8 188.....	Top slab.	5 × 26	1	.15	.027	.017	.52
			2	.21	.041	.026	.57
			3	.14	.026	.017	.52
8 192.....	Top slab.	7 × 18	1	16	.019	.021	.56
			2	.16	.018	.019	.56
			3	.19	.018	.021	.60
10 037.....	Top slab.	6½ × 26	1	.21	.058	.037	.77
			2	.20	.059	.037	.77
			2¾	.20	.053	.040	.81
			3¼	.22	.060	.040	.85
			4	.23	.061	.048	.83
8 201.....	Top slab.	6 × 18	½	.13	.033	.029	.49
			1½	.13	.034	.036	.49
			2½	.12	.034	.032	.49
			3½	.11	.024	.022	.47
	Slab one-third way down the same ingot.	6 × 18	½	.13	.037	.033	.49
			1½	.13	.038	.038	.48
			2½	.14	.046	.047	.49
			3½	.15	.050	.050	.49
8 202.....	Top slab.	6 × 18	½	.11	.030	.022	.42
			1½	.11	.033	.022	.43
			2½	.11	.031	.022	.42
			3½	.11	.031	.022	.43
	Slab one-third way down the same ingot.	6 × 18	½	.12	.039	.023	.43
			1½	.13	.038	.026	.42
			2½	.15	.040	.026	.42
			3½	.15	.048	.048	.42

These results were obtained by drilling slabs rolled from acid open-hearth ingots with a cross-section of 32 × 38 ins., and weighing about 20 000 lbs., such ingots being in common use at Steelton for making slabs for boiler plate and bridge material. The slabs, which were from 5 to 7 ins. thick, were drilled in the middle, and samples of the metal were taken at different depths until the center had been passed. The table shows quite a difference in some cases between the center and the outside of a slab, but it will be con-

sidered that the subsequent rolling into a plate will tend to equalize the composition, and that in any event the center constitutes but a small portion of the total section. In addition to this fear of segregation in large ingots, there is a shadowy feeling in the minds of some engineers as to the homogeneity of a very large heat of steel. In order to satisfy this very reasonable doubt, Table No. 6 gives the records obtained from 20 tests taken at random from the pile of rivet rods from a representative low-phosphorus rivet heat, without any knowledge as to what part of the heat or what part of the ingots the tests came from.

TABLE No. 6.

Tests on Rivet Rounds Taken From Different Parts of the Same Acid Open-Hearth Heat.

Heat No. 10 168. Pennsylvania Steel Company. Weight of Heat, 110 000 lbs. Composition, Per Cent. C. = .12; P. = .013; S. = .024; Mn. = .29; Cu. = .27.

Diameter of bar.	Ultimate strength. Pounds per square inch.		Elastic limit. Pounds per square inch.		Elongation in. 8 ins. Per cent.		Reduction of area. Per cent.	
	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.	Natural.	Annealed.
$\frac{3}{4}$ in....	55 480	49 460	37 600	29 870	32.50	28.75	67.45	65.30
" ..	55 480	49 940	36 670	30 350	32.50	31.25	68.22	65.30
" ..	55 430	49 460	38 400	30 110	33.25	31.75	68.40	67.70
" ..	55 400	49 700	37 250	31 300	30.00	35.00	64.67	69.22
" ..	55 160	49 700	37 950	32 730	30.00	32.50	64.97	69.22
" ..	54 770	50 720	37 600	31 760	32.50	30.00	69.68	64.62
" ..	54 750	50 420	38 400	32 740	33.75	33.75	63.15	61.12
" ..	54 690	50 010	39 120	32 470	32.75	32.50	67.35	67.96
" ..	54 520	50 880	38 640	32 220	33.00	31.25	67.17	67 25
" ..	54 220	49 770	38 900	32 230	33.75	33.75	66.57	69.47
Av'ge.	54 990	50 006	38 054	31 578	32.40	32.05	66.76	66.72
$\frac{7}{8}$ in....	55 000	50 230	37 710	31 950	31.75	33.75	66.31	70.77
" ..	54 780	49 170	37 100	30 310	33.75	36.00	62.83	68.77
" ..	54 700	50 880	36 750	31.620	32.50	34.00	60.11	66.70
" ..	54 180	48 820	37 450	30 840	31.75	35.00	62.30	68.77
" ..	54 170	48 290	36 580	30 840	31.25	34.00	67.83	68.77
" ..	53 880	48 930	36 320	30 730	31.00	36.00	60.20	68.43
" ..	53 770	50 520	35 610	31 670	32.50	34.00	60.02	65.08
" ..	53 770	49 060	35 960	31 120	32.75	35.50	65.73	69.76
" ..	52 860	50 160	35 700	31 920	33.25	35.50	61.39	69.57
" ..	52 600	50 640	35 360	32 400	33.00	35.00	68.49	68.62
Av'ge.	53 970	49 670	36 450	31 340	32.35	34.87	63.52	68.52

The data on the natural bars are arranged in the order of tensile strength, while in parallel columns are given the results obtained by annealing the same bar. Although all the pieces of one heat were heated at the same time and with the utmost care to have all conditions uniform, it will be seen that the variations in the strength of the annealed bar are entirely independent of the variations in the strength of the natural bar. This would indicate that the differences are due to the irregularities in rolling and to determinative errors rather than to any inherent variations in the character of the metal. In further proof of this, drillings were taken from the three annealed bars of heat No. 10 168 which showed the highest tensile strength and from the three which were weakest. The results of analysis are given in Table No. 7.

TABLE No. 7.

Composition of Rivet Rods in Table No. 6, which show the Greatest Differences in the Tensile Strength of the Annealed Bars.

Nature of Piece.	Ultimate strength. Pounds per square inch.		Composition. Per cent.			
	Natural.	Annealed.	C.	P.	S.	Mn.
Preliminary test....	52 280	.....	.12	.013	.024	.29
Average of strongest three bars.....	53 690	50 680	.12	.013	.019	.30
Average of weakest three bars	54 077	48 680	.12	.013	.024	.30

These data on rivet rods may seem rather foreign to the question of the determination of the physical properties, but in reality they are of vital importance; for it is here shown that the most homogeneous steel shows variations in different bars which are not due at all to any fault of the steel or to differences of section, but simply to the accumulation of petty errors, and that the variations so produced may amount to 2 000 lbs. or more per square inch in ultimate strength. This fact is most surely of interest in deciding the limits of variation which are to be allowed in the manufacture of structural material.

In addition to these effects of determinative errors there are differences which are due simply to the shape of the piece. By this is not meant the variations that will be found in pieces cut from shapes of radically different section, but those which may be detected by a care-

TABLE No. 8.

Comparative Physical Properties of ¾-in. Rounds and 2 x ⅜-in. Flats Rolled from the Same Billet.

Limits of ultimate strength. Pounds per square inch.	Kind of steel.	Number of heats in average.	Ultimate strength. Pounds per square inch.		Elastic limit. Pounds per square inch.		Elongation in 8 ins. Per cent.		Reduction of area. Per cent.		Elastic ratio.	
			Round.	Flat.	Round.	Flat.	Round.	Flat.	Round.	Flat.	Round.	Flat.
Natural Bars.												
56 000 to 60 000	Bessemer	11	58 869	58 458	42 318	41 698	27.75	31.45	58.83	56.13	71.88	71.33
	Open hearth	4	58 568	58 130	40 300	40 400	29.69	30.13	60.78	61.75	68.81	69.51
60 000 to 64 000	Bessemer	6	62 087	60 825	45 323	43 135	27.04	30.42	55.31	56.20	73.00	70.92
	Open hearth	7	62 187	62 089	42 606	42 441	28.04	30.14	62.16	60.86	68.51	68.36
64 000 to 68 000	Bessemer	9	66 241	64 621	47 568	45 194	26.08	28.42	50.07	47.80	71.81	69.94
	Open hearth											
68 000 to 72 000	Bessemer	3	70 457	69 773	50 263	49 060	24.75	26.67	48.30	48.40	71.34	70.31
	Open hearth	2	70 530	69 420	49 000	45 090	26.88	25.63	61.10	59.30	69.47	64.96
72 000 to 80 000	Bessemer	11	77 440	76 900	53 760	52 240	24.06	23.44	42.35	40.15	69.42	67.93
	Open hearth	12	76 616	75 865	51 108	49 691	24.52	24.69	53.73	54.40	66.71	65.50
Same Bars Annealed.												
56 000 to 60 000	Bessemer	11	55 703	54 194	37 828	35 603	29.14	30.05	66.55	63.13	67.91	65.70
	Open hearth	4	54 098	51 418	31 823	30 393	28.75	31.06	62.65	60.50	58.82	59.11
60 000 to 64 000	Bessemer	6	59 372	56 192	40 570	37 542	30.13	30.63	65.50	63.38	68.33	66.81
	Open hearth	7	58 364	55 021	35 120	31 576	28.61	30.36	63.47	60.00	60.17	57.39
64 000 to 68 000	Bessemer	9	61 694	58 838	42 228	38 476	28.25	28.36	62.91	59.01	68.45	65.39
	Open hearth											
68 000 to 72 000	Bessemer	3	65 903	64 160	44 660	43 770	26.08	28.58	63.23	59.50	67.76	68.22
	Open hearth	2	65 500	60 850	37 685	34 000	23.38	26.50	55.30	52.10	57.53	55.87
72 000 to 80 000	Bessemer	11	71 548	68 780	47 643	43 568	25.81	26.38	57.53	51.00	66.59	63.34
	Open hearth	12	69 402	67 618	40 505	39 403	23.04	26.31	56.54	51.36	58.36	58.27

ful comparison of pieces which have been worked under very similar conditions. The following investigation examines at some length the physical properties of round and flat test bars. A billet was cut from a large number of Bessemer and open-hearth heats, and one-half of this billet was rolled into a ¾-in. round, and the other half into a 2 x ⅝-in. bar. The results are shown in Table No. 8.

All the lessons of this table are not written on its face, but by examination we may discover the following facts:

First.—Taking into consideration both natural and annealed bars, there are 18 comparisons between rounds and flats. The ultimate strength is less in the flat in every case. The elastic limit falls in 17 cases, and the gain in the exception is slight. The elongation is raised in 16 cases, while in the two exceptions the loss is small. The reduction of area is lowered in 14 cases, and raised in four. The elastic ratio is lowered in 15 cases, while in the exceptions the increase is small.

Second.—Comparing the loss of strength in passing from round to flat, there are nine possible comparisons between the loss in the natural bar and the loss in the annealed piece. The ultimate strength falls more in every case in the annealed than it does in the natural bar. The elastic limit falls in six cases, and rises to a much less extent in three. The elongation rises in five cases, and falls in four. The reduction of area falls in all cases. The elastic ratio falls in five cases, and rises in four.

It will be found that the exceptions and irregularities are not confined to any one kind of steel, so that it would seem proper to average the losses and gains in order to estimate the errors due to the small number of heats in some of the groups. The results of such condensation are given in Table No. 9, which shows the true average of all the heats and not the average of the groups.

It is shown that the loss of ultimate strength from the round to the flat is very much greater in the annealed than in the natural bars, and that the elastic limit more than keeps pace with it, as shown by the elastic ratio. The difference can hardly be due to the effect of varying work, for the round was reduced to 2.6% of the area of the billet, and the flat to 4.7%, the reduction in both cases being so heavy that the results should be uniform as far as this factor is concerned. The effect of the finishing temperature may be ignored in the case of the annealed pieces, and yet there is a difference of 2 448 lbs. per square

TABLE No. 9.

COMPARATIVE PHYSICAL PROPERTIES OF ROUND AND FLAT BARS IN THE NATURAL AND ANNEALED STATES; BEING A SUMMARY OF THE BARS GIVEN IN TABLE No. 8.

Average of all heats given in Table No. 8.	Condition of bar.	Shape of Bar.		Gain = + Loss = −
		Round.	Flat.	In Flat.
Ultimate strength; pounds per square inch.....	Natural.	66 679	65 911	− 768
	Annealed.	62 015	59 567	− 2 448
Elastic limit; pounds per square inch.....	Natural.	46 588	45 268	− 1 320
	Annealed.	39 633	37 106	2 527
Elastic ratio; pounds per square inch.....	Natural.	69.87	68.68	− 1.19
	Annealed.	63.91	62.29	− 1.62
Elongation in 8 ins.; per cent.....	Natural.	26.48	28.22	+ 1.74
	Annealed.	27.16	28.73	+ 1.57
Reduction in area; per cent.....	Natural.	54.98	54.05	− 0.93
	Annealed.	61.98	58.12	− 3.86

inch in ultimate strength between the flat and round. The natural bars show less difference, which would indicate that the effect of the finishing temperature has raised the strength of the flat more than the round. This is contrary to the condition just noted that the reduction in rolling was less in the case of the flat, but it is in accord with the evident fact that a thin bar would cool faster than a round bar of somewhat less sectional area. The effect of the finishing temperature therefore was to raise the tensile strength of the flat more than it did the round, but not enough to overcome the difference in physical properties caused by the shape of the bars. The reduction of area is less in the case of the flat, and the difference is more marked in the annealed than in the natural bars. The elongation is higher in both kinds of flats that in the corresponding rounds, but the difference is greater in the natural bars. This appears at first sight to be an exception, but on further consideration it will be seen that a decrease in gain is equivalent to a loss, and this brings it in accord with the decrease in ductility as shown by the lessened reduction of area. The net result may be summarized as follows:

First.—Flat bars differ from rounds in having less tensile strength, lower elastic limit, lower elastic ratio, greater elongation and a slightly lower reduction of area.

Second.—This difference is caused, not by reason of a different finishing temperature, but in spite of it.

These results show that a certain appreciable variation may arise from a mere difference in the section of the test piece, even where the conditions of rolling or of heat treatment are as constant as can be obtained by more than ordinary care. It will be evident that much greater changes can be produced in the practical manufacture of large sections of varying thicknesses. This will be shown in Table No. 10, which compares the tests on the finished angles from acid open-hearth heats with the results obtained from bars rolled from a 6-in. square test ingot. This preliminary test bar will not give a good elongation owing to insufficient work, but it is found to give closely comparable results in ultimate strength. The relative variations from this, as a standard, will therefore portray the influence of the thickness of the bar.

TABLE No. 10.

COMPARATIVE ULTIMATE STRENGTH OF BARS ROLLED FROM A TEST INGOT, 6 INS. SQUARE (PRELIMINARY TEST), AND TEST PIECES CUT FROM ANGLES OF DIFFERENT THICKNESSES ROLLED FROM THE SAME HEATS. MADE BY THE PENNSYLVANIA STEEL COMPANY.

Thickness of Angle in Inches.	Number of heats.	Ultimate Strength. Pounds per Square Inch.			Elastic Limit. Pounds per Square Inch.			Elastic Ratio.	
		Bar from test ingot.	Bar from angle.	Loss of strength in angle.	Bar from test ingot.	Bar from angle.	Loss of strength in angle.	Bar from test ingot.	Bar from angle.
$\frac{7}{16}$ and $\frac{3}{8}$	39	60 200	60 190	10	42 270	41 300	970	70.23	68.62
$\frac{7}{16}$ and $\frac{1}{2}$	46	61 360	60 660	700	43 070	40 170	2 900	70.19	66 22
$\frac{7}{16}$ and $\frac{5}{8}$	37	62 930	61 520	1 410	42 990	39 710	3 280	68.31	64.55

It is shown that for an increase of $\frac{1}{8}$ in. in thickness there is a diminution in strength of 700 lbs. per square inch. When a large lot of angles or plates are to be rolled of a special thickness, this matter of ultimate strength may be regulated by making a softer or harder steel; but in making a small and miscellaneous lot of sizes and thicknesses, it is evidently impossible to make different heats for each thickness.

TABLE No. 11.

COMPARATIVE PHYSICAL PROPERTIES OF VARIOUS STEELS MADE BY THE PENNSYLVANIA STEEL COMPANY WHEN ROLLED INTO ANGLES OF DIFFERENT THICKNESS.

No. of group	Kind of steel.	Limits of phosphorus in group. Per cent.	Limits of ultimate strength in group. Per cent.	Thickness of angle, in inches.	Number of heats in average.	Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch	Average elastic ratio.	Average elongation in 8 ins. Per cent.	Average reduction of area. Per cent.
I.....	Basic open hearth...	below .04	47 000 to 55 000	$\frac{5}{16}$ to $\frac{1}{2}$	29	52 605	35 910	68.26	32.21	63.85
				$\frac{7}{16}$ to $\frac{7}{8}$	16	52 061	33 405	64 17	33.19	64.20
II.....	Basic open hearth...	below .04	55 000 to 63 000	$\frac{5}{16}$ to $\frac{1}{2}$	22	58 784	39 340	66.92	30.26	59.38
				$\frac{9}{16}$ to $\frac{7}{8}$	6	58 792	37 388	63.60	30.58	56.72
III.....	Acid open hearth...	.05 to .07	56 000 to 64 000	$\frac{5}{16}$ to $\frac{3}{8}$	22	60 443	40 929	67 72	28.66	58 52
				$\frac{7}{16}$ to $\frac{1}{2}$	23	61 173	40 164	65.66	28 72	55.73
				$\frac{9}{16}$ to $\frac{5}{8}$	20	61 318	39 548	64.50	28.31	52.92
				$\frac{11}{16}$ to $\frac{1}{4}$	31	60 609	38 559	63.63	28.62	50.09
IV.....	Acid open hearth....	.07 to .10	56 000 to 64 000	$\frac{5}{16}$ to $\frac{3}{8}$	50	60 064	41 143	68,50	28.82	58.35
				$\frac{7}{16}$ to $\frac{1}{2}$	50	60 583	40 170	66.30	29.05	56.30
				$\frac{9}{16}$ to $\frac{5}{8}$	50	61 049	39 656	64.96	28.98	54.81
				$\frac{11}{16}$ to $\frac{3}{4}$	50	59 763	38 338	64.15	29.60	55.33
				$\frac{13}{16}$ to $\frac{7}{8}$	50	61 129	37 969	62.11	28.85	50.80
V.....	Acid Bessemer.....	.07 to .10	56 000 to 64 000	$\frac{5}{16}$ to $\frac{3}{8}$	150	60 659	43 417	71 58	28.07	56.60
				$\frac{7}{16}$ to $\frac{1}{2}$	200	59 882	42 518	71.00	28.63	56.81
				$\frac{9}{16}$ to $\frac{5}{8}$	200	59 415	41 063	69,11	28.95	55.60
				$\frac{11}{16}$ to $\frac{3}{4}$	200	58 267	38 867	66.70	28.37	51.63
VI.....	Acid open hearth....	.05 to .07	64 000 to 72 000	$\frac{5}{16}$ to $\frac{3}{8}$	12	66 216	43 800	66,15	27.60	54.13
				$\frac{7}{16}$ to $\frac{1}{2}$	21	65 580	42 540	64.87	27.92	54.30
VII.....	Acid open hearth....	.07 to .10	64 000 to 72 000	$\frac{5}{16}$ to $\frac{3}{8}$	24	66 369	44 480	67.02	27.13	55.64
				$\frac{7}{16}$ to $\frac{1}{2}$	35	65 856	42 846	65.06	27.42	53.15
VIII.....	Acid Bessemer.....	.07 to .10	64 000 to 72 000	$\frac{5}{16}$ to $\frac{3}{8}$	50	66 359	46 512	70.09	26.36	50 15
				$\frac{7}{16}$ to $\frac{1}{2}$	23	65 940	45 280	68.66	27.30	51.52

Fortunately, the differences in ultimate strength are usually not very marked, although they do often give rise to more or less trouble. The variations in elastic limit and reduction of area are not so trivial, as may be seen in Table No. 11, which gives the average results from angle bars of several different kinds of steel. No comparison of the ultimate strength is possible, for each bar is from a different heat; but as all the steels in any group were made in the same department, and all were rolled in the same mill and tested in the same laboratory, the other factors may be regarded as fairly comparable.

It will be seen that there is a reasonably regular law that the elastic ratio and reduction of area decrease with increasing thickness, while the elongation remains the same. In the same way that the physical properties vary in angles of different thicknesses, so will they be different in angles and plates. This will be illustrated by Table No. 12, which compares the results obtained from the steel made by The Pennsylvania Steel Company when rolled into angles and plates. In both cases there is no selection of tests, but all pieces, good, bad and indifferent, are taken as they appear upon the records.

TABLE No. 12.

Comparative Physical Properties of Angles and Sheared Plates, both being made from Steel made by The Pennsylvania Steel Company.

Thickness of bar.	Kind of piece.	Number of heats in average.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
Basic Open-Hearth Soft Steel.							
$\frac{5}{16}$ to $\frac{3}{8}$	Angles	31	55 718	38 105	68.39	30.92	62.3
	Plates	156	56 430	40 984	72.63	27.86	57.3
$\frac{7}{16}$ to $\frac{1}{2}$	Angles	17	55 307	35 919	64.94	31.78	60.9
	Plates	20	55 335	36 290	65.58	29.91	57.2
Basic Open-Hearth Medium Steel.							
$\frac{5}{16}$ to $\frac{3}{8}$	Angles	17	58 383	39 657	67.93	30.47	60.4
	Plates	107	59 630	43 356	72.71	27.11	57.7
Acid Open-Hearth Soft Steel.							
$\frac{3}{8}$	Angles	42	59 843	40 721	68.05	28.92	58.4
	Plates	12	61 961	42 567	68.70	25.48	51.0
$\frac{7}{16}$ to $\frac{1}{2}$	Angles	50	60 583	40 170	66.30	29.05	56.3
	Plates	53	60 711	39 690	65.38	24.56	51.4

This shows that a less percentage of elongation can be expected from a plate than from an angle of the same thickness. No data are given of plates thicker than ½ in., but it is quite clear that, when all other things are equal, an increase in thickness is accompanied by a reduction in the ductility. The heads of two widely known plate mills have given the author as their estimate that, taking ½ in. as a basis, there will be the following changes in the physical properties for every increase of ¼ in. in thickness:

First.—A decrease in ultimate strength of 1 000 lbs. per square inch.

Second.—A decrease in elongation of 1%, when measured in an 8-in. parallel section.

Third.—A decrease in reduction of area of 2 per cent.

It should also be mentioned that in the case of plates less than $\frac{5}{16}$ in. in thickness, the test will give a high ultimate strength and a low ductility. In order to do away with the variations in the physical properties of different shapes, it has been proposed that the steel be accepted or rejected on the result of what is known as the "preliminary test," *i. e.*, a bar rolled from a small test ingot. No less an authority than Mr. A. E. Hunt has advocated this method,* claiming that it is "convenient," and that it is the "fashion." Consequently, Mr. Hunt would accept the steel on the "preliminary test, provided that the finished material comes within 4% of the standard thus obtained."

It seems to the author that this provision is a *reductio ad absurdum*, for if the finished material is to be tested at all, what has the "preliminary" to do with the question? It is true that it is the "fashion" to make such a test, and nowhere more than at Steelton, but this is done to prevent mistakes. We find that the ultimate strength of the test represents the ultimate of the finished bars, and without regard to any results on elongation or other qualities, we use or lay aside the charge. We are perfectly willing that the inspectors should see all the results, but we claim that it has nothing to do with the acceptance or rejection of the material. We prefer to roll a flat bar rather than a round, since this form allows drifting or bending tests, although it is recognized that the elongation and reduction of area will be different in flats and rounds. In other words, this test is our own work, and the business of the inspector is to test the material that he buys as

* See the *Journal* of the Iron and Steel Institute, Vol. II, 1890.

fully and carefully as he may wish, without regard to whether a small test ingot has or has not fulfilled certain requirements, or whether it has been made at all. Convenience has no place in this matter, save where it is a mutual arrangement to the satisfaction of all concerned, whereby unnecessary delay and friction may be avoided. Our experience in comparing results from the preliminary test with those from the finished material differs radically from that recorded by Mr. Hunt for the elongation and reduction of area are much inferior in the small test. We fully understand that this is on account of the method of working, but we know also that any change would result in less uniformity in the matter of ultimate strength, which is of great importance to us, and we claim the right to do as we wish with this test, granting to the engineer the right to do as he wishes with the finished material.

Another method by which it is hoped to overcome the effect of varying shape is to make the length a function of the sectional area. The formula which is advocated by the Committee of the American Society of Mechanical Engineers is—

$$L = 12\sqrt{F}$$

where L = the length in inches,

and F = the sectional area in square inches.

Thus in the case of rounds, for example, the length of the test piece will increase with every increase in diameter, which is the same thing as saying that for an equal length of piece an increased elongation will be demanded. In view of this advocacy of varying length, the information which has been published on the influence of changes in length upon the percentage of elongation is not as accurate as might be wished. The results of M. Barba* have long been accepted as authoritative, and they are given in Table No. 13.

Not satisfied with these experiments, the writer conducted the following investigation: Twenty rods ¾ in. in diameter were selected from one heat of acid open-hearth steel. From each rod seven bars were cut, one of which was tested in a length of 2 ins., and one each in 4, 6, 8, 10, 12 and 14 ins. The results are given in Table No. 14.

Fig. 1 shows these data and those from Barba, when plotted in curves.

* See the *Mémoires* of the Society of Civil Engineers of France, Vol. I, 1880.

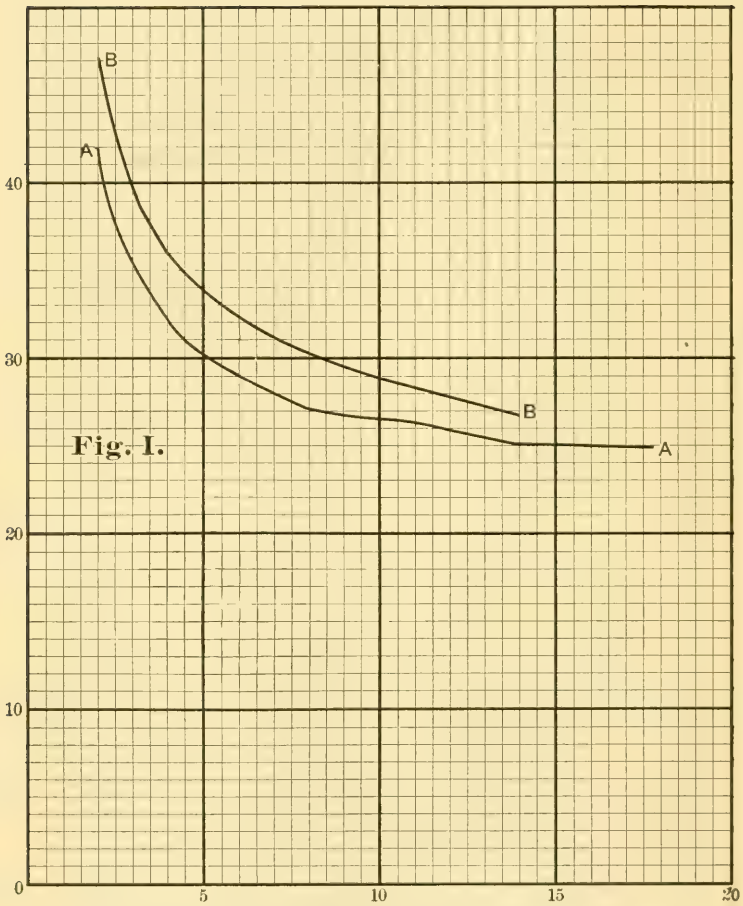

Fig. I.

EFFECT OF A CHANGE IN THE LENGTH OF THE TEST PIECE UPON THE ELONGATION.

Curve A A from Barba (See Table 13)
Curve B B from P.S.Co. (See Table 14)
Abscissas = Length, in inches.
Ordinates = Elongation, per cent.

TABLE No. 13.

INFLUENCE UPON THE ELONGATION OF A CHANGE IN THE LENGTH OF THE TEST PIECE, THE DIAMETER REMAINING CONSTANT.

Number of bar.	Dimensions in Inches.		Ratio of length to diameter.	Elongation. Per cent.
	Length.	Diameter.		
1	1.97	0.677	2.91	42.0
2	3.94	0.677	5.81	32.0
3	5.91	0.677	8.72	29.3
4	7.87	0.677	11.60	27.2
5	9.84	0 677	14.50	26.6
6	11.81	0.677	17.40	26.0
7	13.78	0.677	20.30	25.1
8	15.75	0.677	23.30	25.0
9	17.72	0.677	26.20	24.9

This law of decrease in elongation with increase in length holds good in extreme lengths, as will be shown by Table No. 15, which gives the result of averaging a large number of eye-bar tests, for which the author is indebted to the Union Bridge Company.

TABLE No. 14.

INFLUENCE UPON THE PHYSICAL PROPERTIES OF A CHANGE IN THE LENGTH OF THE TEST PIECE.

Pennsylvania Steel Co. Acid Open-Hearth Steel. Each figure is the average of 20 tests.

Length of test piece in inches.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Elongation in in 8 ins. Per cent.	Reduction of Area. Per cent.
2	60 685	42 548	70.11	47.43	66.7
4	60 343	43 134	71.48	36.11	66.9
6	60 099	42 951	71.47	32.17	67.1
8	60 123	43 159	71.78	30.16	66.8
10	60 068	43 161	71.85	28.96	67.3
12	60 059	43 024	71.64	27.87	67.2
14	60 066	43 234	71.98	26.76	67.1

In addition to the changes that may be produced by varying the length of the test piece, the width of the specimen has a bearing upon the result. For the purposes of experiment five strips of different widths were cut side by side from specimen plates of 30 different heats. The results are given in Table No. 16, and the conclusions therefrom may be summarized as follows :

TABLE No. 15.

PHYSICAL PROPERTIES OF EYE-BARS, CLASSIFIED ACCORDING TO LENGTH. MADE BY THE UNION BRIDGE COMPANY.

Number of heats represented.	Limits of length in group. In feet.	Average length of group. In feet.	Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch.	Elongation in full length. Per cent.	Elongation in the 12 ins., including the fracture. Per cent.	Reduction of area. Per cent.
41...	10 to 12	11.8	59 880	35 240	18.07	34.68	46.95
102...	13 to 16	14.8	59 830	35 460	18.05	35.75	48.43
215...	17 to 20	18.6	59 770	35 540	16.58	35.04	48.37
245...	21 to 25	22.9	60 380	35 460	15.75	35.37	47.72
145...	26 to 30	28.0	59 520	35 310	15.37	36.36	49.25
82...	31 to 35	33.1	59 900	35 470	14.17	34.73	49 85
830...	All lengths.	.....	59 930	35 440	.....	35.41	48.42

First.—Variations in the width of the test piece have very little effect upon the ultimate strength.

Second.—They probably have little influence upon the elastic limit. The narrow pieces show a decided increase in the elastic ratio, but this needs further corroboration.

Third.—They have little effect upon the reduction of area, but a slight deterioration is indicated with increase of width.

Fourth.—The elongation improves as the width increases.

This fact is well understood by manufacturers, and for this reason there is a tendency toward the use of very strong machines, for in this manner a thick plate may be tested in a wide bar, and thus give a better result. This cannot be called unfair, but the results are misleading when compared with those of other works. The whole proceeding can be stopped by limiting the sectional area of the test piece to an ordinary figure. Still another point which influences the recorded physical properties is the pulling speed of the machine. This is illustrated in Table No. 17, where it is shown that a decrease in speed is accompanied by a decrease in ultimate strength, elastic limit, elastic ratio, and elongation. In the case of the slowest speed, there is a marked exception to this rule, but this point is not of great practical importance since it requires nearly an hour to break a single bar of ductile steel at this speed.

TABLE No. 16.

EFFECT OF CHANGES IN THE WIDTH OF THE TEST PIECE UPON THE PHYSICAL PROPERTIES. AVERAGE OF STRIPS FROM SHEARED PLATES FROM 30 HEATS OF THE PENNSYLVANIA STEEL COMPANY STEEL.

Width of test piece in inches.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of Area. Per cent.
½	70 578	46 284	65.58	23.87	59.43
¾	69 872	44 022	63.00	25.21	58.46
1	69 967	43 579	62 29	26.25	58.29
1½	70 176	43 588	62.11	27.25	58.09
2	70 068	43 570	62.18	27.92	56.20

TABLE No. 17.

EFFECT OF VARIATIONS IN THE PULLING SPEED OF THE TESTING MACHINE UPON THE RECORDED RESULTS, MADE BY THE PENNSYLVANIA STEEL COMPANY.

Pulling speed. Inches per minute.	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
4.50	61 075	45 708	74.84	30.32	64 96
3.00	60 672	44 410	73.20	30.18	64.83
0.67	59 523	42 904	72.08	29.45	65.82
0 38	59 387	41 763	70.32	29.33	65.69
0.07	59 027	39 647	67.17	31.93	66.48

The natural result of this investigation would be a tendency toward higher breaking speed. It is believed, however, that this may be carried too far, since with fast work it is more difficult to take accurate readings. The one important point to keep in mind is to have the details of testing as nearly uniform as possible among all manufacturers in order that each make of steel shall stand on its own merits.

CLASSES RECOMMENDED.

It is not the intention of this paper to state arbitrarily just what should or should not be given as the best tensile strength for every purpose, but it is the opinion of the author that a softer metal than is

often employed should be used for bridges, because although a slight sacrifice is made in the ultimate strength this is partly offset by the higher elastic ratio and a decided increase in toughness and resistance to shock, so that the calculations may be made on the same basis for the working load as with a harder metal. The fact that the elastic ratio rises as the ultimate strength decreases is not generally recognized, but will be shown in Table No. 18. This is constructed by comparing the groups of angles in Table No. 11, which are made by the same process, of the same thickness, and which contain the same percentage of phosphorus. It will be found that in every case the stronger steel gives a lower elastic ratio. The tendency in the first

TABLE No. 18.

RISE IN ELASTIC RATIO WITH DECREASE IN ULTIMATE STRENGTH. COMPARISON OF THE ANGLES IN TABLE No. 11, WHICH ARE MADE BY THE SAME PROCESS, OF THE SAME THICKNESS, AND WITH THE SAME CONTENT OF PHOSPHORUS.

Kind of steel.	Content of phosphorus. Per cent.	Thickness of angle in inches.	Harder Steels.			Softer Steels.			Rise in elastic ratio in softer steels. Per cent.
			Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch.	Average elastic ratio. Per cent.	Average ultimate strength. Pounds per square inch.	Average elastic limit. Pounds per square inch.	Average elastic ratio. Per cent.	
Basic open-hearth...	below 0.04	$\frac{5}{16}$ to $\frac{3}{8}$	58 784	39 340	66.92	52 605	35 910	68.26	1.34
		$\frac{7}{16}$ to $\frac{1}{2}$	58 792	37 388	63.60	52 061	33 405	64.17	0.57
Acid open-hearth....	0.05 to 0.07	$\frac{5}{16}$ to $\frac{3}{8}$	66 216	43 800	66.15	60 443	40 929	67.72	1.57
		$\frac{7}{16}$ to $\frac{1}{2}$	65 580	42 580	64.87	61 173	40 164	65.66	0.79
Acid open-hearth....	0.07 to 0.10	$\frac{5}{16}$ to $\frac{3}{8}$	66 369	44 480	67.02	60 064	41 143	68.50	1.48
		$\frac{7}{16}$ to $\frac{1}{2}$	65 856	42 846	65.06	60 583	40 170	66.30	1.24
Acid Bessemer	0.07 to 0.10	$\frac{5}{16}$ to $\frac{3}{8}$	66 359	46 512	70.09	60 659	43 417	71.58	1.49
		$\frac{7}{16}$ to $\frac{1}{2}$	65 940	45 280	68.66	59 882	42 518	71.00	2.34

epoch of steel structures was toward a hard alloy, but the later practice has been a continual progress toward toughness. There was a halt in this movement at a tensile strength of 60 000 lbs., not entirely on account of any magic virtue in that figure, but because the ordinary mild steels gave that result, and a much higher price was charged for a softer metal. Later improvements in manufacture and the introduction of the basic hearth have altered the economic situation. A steel with a tensile strength of 50 000 to 58 000 lbs. per square inch is a most

attractive material, possessing all the good characteristics of wrought iron with greater strength and toughness, and it seems probable that it will be extensively used in the future.

With this recommendation for the adoption of softer metal certain classes are proposed from which the engineer can choose. In some cases the option is given between acid and basic open-hearth steel, but it must not be forgotten that it costs more to make pure metal by the acid than by the basic process, so that the terms of the specification should be enforced after the contract is awarded out of justice to the other bidders who have based their calculations on the letter of the law. In steel above .08% phosphorus this difference in cost disappears, and there is no economy in the use of the basic hearth. The option is sometimes given between open-hearth and Bessemer metal, but it will be understood that whenever the former is specified, the latter is not admissible, although as a matter of course the manufacturer may supply open-hearth in place of Bessemer if for any reason he wishes to use the better and more expensive material. In the specifications for plates it will be noticed that a variation of 10 000 lbs. per square inch is allowed, and that concessions are made for thick and wide sections. All this may seem to some engineers to be a step backward, but in reality these provisions have been in force for many years.

The engineer who writes a new specification calling for a better elongation never knows that he receives exactly the same steel that has been made before. The plate rollers have been driven to expedients which are not dishonest, but which are dangerously near the line of deception. Thus, if it is required that a test must be cut from one plate out of every ten, the manufacturer will leave a coupon on every plate and will test strips which are cut from immediately next to them; after finding which plates fill the requirements, the coupons are cut from the others and the inspector is told that the pile is ready for him. If every plate is to be tested, then a coupon is left upon each corner and a contiguous strip is privately tested by the maker. After finding which corner gives the best results, the other coupons are cut off and the plate submitted to the inspector. This is not dishonest, for any one corner represents the plate just as much as any other corner, and it would manifestly be absurd to designate from which corner the test is to be taken. It is also quite certain that no one corner represents the center of the plate, for the edges are always finished colder than the

center, and it is just as certain that in a plate rolled direct from an ingot with only the usual amount of scrap, the corners in no way represent the part of the plate which corresponds to the segregated portion of the ingot. It is by care in the preliminary testing almost as much as in improvement in the quality of the material that advances have been made, and it is time that the fact be made known to engineers. The mill managers have been aided by the inspectors, for most of these men (to their credit be it said) are anxious to pass material which they know to be good. They allow the manufacturer to put part of a heat into thick plates and part into thin, and make the tests on the $\frac{3}{8}$ or $\frac{1}{2}$-in. gauges; they pass over the sheets that are 100 ins. wide and cut the coupons from plates that are less than 70 ins. wide. These concessions have been tacitly made in the past. The author has merely put them into print. On the other hand he has called for higher tests on plates under 42 ins. wide. This is because they can be made on a universal mill; and since better results can be had in this way, it is right to demand what there is a perfectly simple way of obtaining. It will be seen that no allowance is made for a variation in tensile strength for different shapes, while concessions are made for differences in thickness. This inconsistency arises from the fact that it is generally known beforehand whether a certain heat of steel is to be rolled into angles, or plates, or eye-bars, and it is seldom that it is necessary to put part of a heat into one shape and part into another. On the other hand it is almost always necessary to roll a charge into more than one thickness and more than one size of angles, plates, etc., and it is evidently an onerous restriction if proper allowance be not made for the normal variations due to different thicknesses.

Throughout the schedule the term "elastic limit" is used and not the new phrase "yield point." The author has no sympathy with that group of agitators who are trying to do what has so many times been proven to be impossible, to change a trade nomenclature without causing endless confusion. The absurd part of the whole business is that no attempt is made to create a new standard, but simply to change a name. If this were all, the effort would be of little import, but when it is proposed to appropriate the term "elastic limit" and make it denote a new point which is registered by certain autographic devices that are attached to some testing machines, then it is time to say that only harm can result from such misdirected efforts. Whether this

autographically registered point is or is not the true elastic limit is a matter in which we have a certain scientific interest, but let its parents christen it with a new name and not steal a term which is pre-empted by the copyright of general use.

General Provisions on Methods of Testing.

First.—Rivet rods and other rounds are to be tested in the form in which they leave the rolls, without machining.

Note.—This is apparently opposed to the recommendations of the International Congress,* wherein it is proposed that round test pieces should be turned to one of four standard diameters, with shoulders and screw grips threaded at each end; but it is stated elsewhere in the Reports of the Committee that only pieces for scientific investigation are to be prepared in this manner.

Second.—Test pieces from angles, plates, shapes, etc., shall be rectangular in shape, with a cross-sectional area of about ½ sq. in., and shall be taken so that only two sides are machine-finished, the other two having the surface which was in contact with the rolls in the last pass.

Note.—The report of the Committee above mentioned recommends this method of cutting tests, but specifies that there shall be shoulders at each end. This necessitates considerable extra machine work without any notable effect upon the result. The limitation of the area of the piece prevents the passing of inferior material by an unusual increase in width.

Third.—Should fracture occur outside of the middle third of the gauge length, the test is to be discarded as worthless if it falls below the standard.

Note.—This provision is copied from the report of the Committee on Standard Tests of the American Society of Mechanical Engineers and is much to be commended. A deficient elongation when the piece breaks near the end is not the fault of the material, but a mere accident. On eye-bars, a failure in the eye should condemn the method of forming the head rather than the quality of the steel.

Fourth.—In case one test piece falls slightly below the requirements in any particular, the inspector shall allow the retesting of the lot or heat by taking four additional tests from the same lot or heat, and if

* See the Report of the Committee on Standard Tests of the American Society of Mechanical Engineers, Appendix V.

the average of the five shall show that the steel is well within the requirements, the material shall be accepted.

Fifth.—Drillings for chemical analysis may be taken either from the preliminary test piece or from the finished material, but if the sample be taken from the center of a sheared or universal mill plate, the maximum limit of both phosphorus and sulphur shall be raised 25%, viz., from 0.04 to 0.05%, or 0.08 to 0.10 per cent.

Sixth.—The pulling speed of the machine for breaking test pieces shall not be less than ½ in. per minute, nor more than 3 ins. per minute.

CLASS I.—Extra Dead Soft; for common rivets, wire cables, and other purposes where exceptional toughness is required.

Method of Manufacture.—Basic open-hearth process.
Chemical Composition, in per cent.—P below .04; S below .06; Si below .05; Mn below .65.
Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate Strength, Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
		Minimum.	Maximum.			
Rivet rods.....	[illegible]	46 000	55 000	64.0	28.0	52
"	[illegible]	46 000	54 000	63.0	29.0	58
"	[illegible]	45 000	54 000	61.5	29.25	56
"	1	45 000	54 000	60.0	29.50	54
"	1¼	44 000	54 000	58.5	29.75	52
"	1½	44 000	54 000	57.0	30.00	50

A rolled round about ¾ in. in diameter, after being nicked about one-quarter way through, shall bend completely double without fracture, with the nick on the outer curve of the bend.

Heats rolled into bars less than ⅝ in. in diameter may be tested in trial rods of ¾ in.

If any bar fails to pass the physical tests, four more pieces shall be taken from the same heat and the average of all five bars shall be considered the true record.

Class II.—Bridge Rivets; for rivets in railroad bridges.

Method of Manufacture.—Acid or basic open-hearth process.
Chemical Composition, in per cent.—P below .04 in acid steel, below .03 in basic; S below .05; Si below .05; Mn below .65.

Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 Ins. Per Cent.		Average reduction of area. Per cent.
		Minimum.	Maximum.		Average.	Minimum.	
Rivet rods..	$\frac{5}{8}$	48 000	57 000	66.0	29.0	27.0	60
" ..	$\frac{3}{4}$	48 000	56 000	65.0	30.0	28.0	60
" ..	$\frac{7}{8}$	47 000	56 000	63.5	30.5	28.5	58
" ..	1	47 000	56 000	62.0	31.0	29.0	56
" ..	$1\frac{1}{8}$	46 000	56 000	60.5	31.0	29.0	54
" ..	$1\frac{1}{4}$	46 000	56 000	59.0	31.0	29.0	52

Two tons of bars from the same heat shall constitute a lot, and two specimens, each from a different bar, shall be tested from each lot. The above table gives the average required of these two bars, and the minimum below which no bar shall fall. If the average elongation or reduction of area on any one lot shall fall below the requirement, two additional bars shall be cut from the same lot, and the average of the four pieces shall be considered the average of the lot, provided that no concession be made in the minimum. Heats rolled into sizes less than $\frac{5}{8}$ in. may be tested in trial rods of $\frac{3}{4}$ in.

A rolled round about $\frac{3}{4}$ in. in diameter, after being nicked one-quarter way through, shall bend completely double without fracture, with the nick on the outer curve of the bend. A piece of $\frac{3}{4}$-in. rod cut $\frac{1}{2}$ in. long shall be upset while cold into a disc $\frac{1}{8}$ in. thick, without developing extensive flaws or showing signs of cold shortness.

Class III.—Hard Bridge Rivets; a substitute for Class II, giving greater strength with less toughness.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition, in per cent.—P below .04 in acid steel, below .03 in basic; S below .05; Si below .05; Mn below .65.

Physical requirements as follows:

Shape.	Diameter in inches	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 Ins. Per Cent.		Average reduction of area. Per cent.
		Minimum.	Maximum.		Average.	Minimum.	
Rivet rods..	$\frac{5}{8}$	54 000	63 000	61.0	28.0	26.0	55
" ..	$\frac{3}{4}$	54 000	62 000	60.0	29.0	27.5	55
" ..	$\frac{7}{8}$	53 000	62 000	58.5	29.5	27.5	53
" ..	1	53 000	62 000	57.0	30.0	28.0	51
" ..	$1\frac{1}{8}$	52 000	62 000	55.5	30.0	28.0	49
" ..	$1\frac{1}{4}$	52 000	62 000	54 0	30.0	28.0	47

Two tons of bars from the same heat shall constitute a lot, and two specimens, each from a different bar, shall be tested from each lot. The above table gives the average required of these two bars, and the minimum below which no bar shall fall. If the average elongation or reduction of area on any one lot shall fall below the requirement, two additional bars shall be cut from the same lot, and the average of the four pieces shall be considered the average of the lot, provided that no concession be made in the minimum. Heats rolled into sizes less than $\frac{5}{8}$ in. may be tested in trial rods of $\frac{3}{4}$ in.

Class IV.—Common Hard Rivets; for roof trusses and other structures not exposed to shock.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .05; Si below .05; Mn below .65.

Physical requirements as follows:

Shape.	Diameter in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.
		Minimum.	Maximum.			
Rivet rods.....	$\frac{5}{8}$	54 000	63 000	61.0	27.0	55
"	$\frac{3}{4}$	54 000	62 000	60.0	28.0	55
"	$\frac{7}{8}$	53 000	62 000	58.5	28.5	53
"	1	53 000	62 000	57.0	29.0	51
"	$1\frac{1}{8}$	52 000	62 000	55.5	29.0	49
"	$1\frac{1}{4}$	52 000	62 000	54.0	29.0	47

Four tests shall be taken from each heat, and the average of these four shall conform to the above table. If the average elongation or reduction of area of any heat shall fall below the requirement, four additional bars may be cut from the same heat, and the average of the eight pieces shall be considered the average of the heat. Heats rolled into sizes less than $\frac{5}{8}$ in. may be tested in trial rods of $\frac{3}{4}$ in.

CLASS V.—Soft Bridge Steel; for angles, plates, bars, etc., for bridges, cranes, and similar structures exposed to shock.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .60.

Physical requirements as follows:

Shape.	Thickness in inches.	Ultimate Strength. Pounds per Square Inch. Minimum.	Ultimate Strength. Pounds per Square Inch. Maximum.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Remarks.
Angles...		50 000	58 000	63.0	29.0	55	One piece of $\frac{3}{4}$-in. angle must open out flat and another close shut without sign of fracture.
" ...		50 000	58 000	61.5	29.0	53	
" ...		49 000	58 000	60.0	29.0	51	
" ...		49 000	58 000	58.5	29.0	49	
" ...		48 000	58 000	57.0	29.0	47	
Plates....	$\frac{5}{16}$	53 000	63 000	65.0	23.0	44	On plates under 42 ins. wide the required elongation shall be raised 1.5% and the reduction of area 2.0 per cent. On plates over 70 ins. wide the elongation shall be lowered 1.5% and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5% and 15 per cent. Both longitudinal and transverse strips cut from plates shall bend double flat. When every plate in the heat is tested, the minimum elongation and reduction shall be lowered 5 per cent.
"	$\frac{3}{8}$	51 000	61 000	63.0	26.0	50	
"	$\frac{1}{2}$	50 000	60 000	62.0	26 0	50	
"	$\frac{3}{4}$	49 000	59 000	60.0	25.0	48	
"	1	48 000	58 000	58.0	24.0	46	
"	$1\frac{1}{4}$	47 000	58 000	56.0	23.0	44	
Eye-bars annealed.	$\frac{3}{4}$	50 000	58 000	57.0			The elongation in full length shall be 15% in bars from 10 to 20 ft. long, 14% in 21 to 25 ft., 13.5% in 26 to 30 ft., and 13% in 31 to 35 ft.
" ..	1	50 000	58 000	56.0			
" ..	$1\frac{1}{4}$	49 000	58 000	54.0			
" ..	2	49 000	58 000	53.0			
" ..	$2\frac{1}{2}$	48 000	58 000	52.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

CLASS VI.—Medium Bridge Steel; a substitute for Class V when greater strength and less toughness are required.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .65

Physical requirements as follows :

Shape.	Thickness in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Remarks.
		Minimum.	Maximum.				
Angles...	$\frac{5}{16}$	56 000	64 000	63.0	27.0	50	One piece of angle, not over ½ in. thick, shall open out flat, and another close shut without sign of fracture.
" ...	$\frac{3}{8}$	56 000	64 000	61.5	27.0	48	
" ...	$\frac{1}{2}$	55 000	64 000	60.0	27.0	46	
" ...	$\frac{5}{8}$	55 000	64 000	58.5	27.0	44	
" ...	$\frac{3}{4}$	54 000	64 000	57.0	27.0	42	
Plates....	$\frac{5}{16}$	59 000	69 000	62.0	22.0	39	On plates under 42 ins. wide the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. On tests cut cross-wise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5%, and 15 per cent. Longitudinal strips shall bend double flat; transverse strips shall bend through 180° around a pin 1 in. in diameter. When every plate in the heat is tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
"	$\frac{3}{8}$ to $\frac{3}{4}$	57 000	67 000	60.0	25.0	45	
"	$\frac{3}{4}$ to 1	56 000	66 000	59.0	25.0	45	
"	1 to $1\frac{1}{4}$	55 000	65 000	57.0	24.0	43	
"	$1\frac{1}{4}$ to $1\frac{1}{2}$	54 000	64 000	55.0	23.0	41	
"	$1\frac{1}{2}$ to 2	53 000	64 000	53.0	22.0	39	
Eye-bars annealed.	$\frac{3}{4}$ to 1	56 000	64 000	56.0			The elongation in full length shall be 14% in bars from 10 to 20 ft. long, 13% in 21 to 25 ft., 12.5% in 26 to 30 ft., and 12% in 31 to 35 ft.
" .	1 to $1\frac{1}{2}$	56 000	64 000	55.0			
" .	$1\frac{1}{2}$ to 2	55 000	64 000	53.0			
" .	2 to $2\frac{1}{2}$	55 000	64 000	52.0			
" .	$2\frac{1}{2}$ to 3	54 000	64 000	51.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

NOTE.—The allowable content of phosphorus may be raised to .08% for acid, and .05% for basic steel, if the best quality is not required, but other specifications must remain the same.

Class VII.—Hard Bridge Steel.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .80.

Physical requirements as follows :

Shape.	Thickness in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Remarks.
		Minimum.	Maximum.				
Angles ...	5/16	60 000	68 000	62.0	26.0	48	One piece of angle, less than ½ in. thick, shall open out flat, and another piece close shut without sign of fracture.
" ...	½	60 000	68 000	60.5	26.0	46	
" ...	⅝	59 000	68 000	59.0	26.0	44	
" ...	¾	58 000	68 000	57.5	26.0	42	
" ...	⅞	57 000	68 000	56.0	26.0	40	
Plates....	5/16	63 000	73 000	60.0	20.0	34	On plates under 42 ins. wide the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5%, and 15 per cent. Longitudinal strips shall bend double flat. Transverse strips shall bend through 180° around a pin 1 in. in diameter. When every plate in the heat is to be tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
"	½	61 000	71 000	58.0	23.0	40	
"	⅝	60 000	70 000	57.0	23.0	40	
"	¾	59 000	69 000	55.0	22.0	38	
"	1	58 000	68 000	53.0	21.0	36	
"	1¼	57 000	68 000	51.0	20.0	34	
Eye-bars annealed.	¾	60 000	68 000	55.0	The elongation in full length shall be 13% in bars from 10 to 20 ft. long, 12.5% in 21 to 25 ft., 12% in 26 to 30 ft., and 11.5% in 31 to 35 ft.		
" .	1	60 000	68 000	54.0			
" .	1½	59 000	68 000	52.0			
" .	2	59 000	68 000	51.0			
" .	2½	58 000	68 000	50.0			

Shapes.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

Note.—The allowable content of phosphorus may be raised to .08% in acid, and .05% in basic steel, if the best quality is not required, but other specifications must remain the same.

CLASS VIII.—Extra Hard Bridge Steel; for special structures where great stiffness is essential.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .80.

Physical requirements as follows:

Shape.	Thickness in inches.	Ultimate Strength. Pounds per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Remarks.
		Minimum.	Maximum.				
Angles....		64 000	72 000	61.0	25.0	45	One piece of angle, about $\frac{3}{4}$ in. thick, shall open out flat, and another piece close shut without sign of fracture.
"		64 000	72 000	59.5	25.0	43	
"		63 000	72 000	58.0	25.0	41	
"		62 000	72 000	56.5	25.0	39	
"		61 000	72 000	55.0	25.0	37	
Plates....							On plates under 42 ins. wide, the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. On tests cut cross-wise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5% and 15 per cent. Longitudinal strips shall bend double flat. When every plate in the heat is to be tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
"	$\frac{5}{16}$	67 000	77 000	59.0	18.0	32	
"		65 000	75 000	57.0	21.0	38	
"		64 000	74 000	56.0	21.0	38	
"		63 000	73 000	54.0	20.0	36	
"	1	62 000	72 000	52.0	19.0	34	
	$1\frac{1}{4}$	61 000	72 000	50.0	18.0	32	
Eye-bars annealed.	$\frac{3}{4}$	64 000	72 000	54.0			The elongation in full length shall be 12.5% in bars from 10 to 20 ft. long, 12.0% in 21 to 25 ft., 11.5% in 26 to 30 ft., and 11.0% in 31 to 35 ft.
" ..	1	64 000	72 000	53.0			
" ..	$1\frac{1}{2}$	63 000	72 000	51.0			
" ..	2	63 000	72 000	50.0			
" ..	$2\frac{1}{2}$	62 000	72 000	49.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowances for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

NOTE.—The allowable content of phosphorus may be raised to .08% for acid steel, and .05% for basic, if the best quality is not required, but other specifications must remain the same.

Class IX.—Forging Steel; for pins and miscellaneous forgings and for special plates and angles.

Method of Manufacture.—Acid or basic open-hearth process.

Chemical Composition in per cent.—P below .06 in acid steel, below .04 in basic; S below .10; Si below .10; Mn below .90.

Physical requirements as follows:

Shape.	Thickness in Inches.	Ultimate Strength Pounds Per Square Inch.		Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	Remarks.
		Minimum.	Maximum.				
Angles....	[illegible]	70 000	80 000	58.0	22.0	42	One piece of angle $\frac{3}{4}$ in. thick shall open out flat, and another piece close shut without sign of fracture.
"		70 000	80 000	56.5	22.0	40	
"		69 000	80 000	55.0	22.0	38	
"		68 000	80 000	53.5	22.0	36	
"		67 000	80 000	52.0	22.0	34	
Plates....	$\frac{5}{16}$	73 000	83 000	56.0	16.0	30	On plates under 42 ins. wide the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. Longitudinal strips under $\frac{1}{2}$ in. thick shall bend double flat. When every plate in the heat is to be tested, the minimum elongation and reduction of area shall be lowered 5 per cent.
"	$\frac{7}{16}$–$\frac{3}{4}$	71 000	81 000	54.0	19.0	36	
"		70 000	80 000	53.0	19.0	36	
"		69 000	79 000	51.0	18.0	34	
"	1	68 000	78 000	49.0	17.0	32	
"	$1\frac{1}{4}$	67 000	78 000	47.0	16.0	30	

When this steel is used for pins or forgings, a charge may be tested by rolling a small test ingot or piece of bloom into a bar with a cross-section of about 0.5 or 1.0 sq. in. This bar should have an ultimate strength of between 70 000 and 80 000 lbs. per square inch, an elastic ratio of 58%, and an elongation of 15% in 8 ins. This method will usually suffice to show the quality of the steel. If it is desirable to test the forged work, a bar should be cut from a rolled or hammered piece about 6 ins. in smallest dimension, and turned to a $\frac{3}{4}$-in. round, 2 ins. between shoulders. This should have an ultimate strength of between 67 000 and 80 000 lbs. per square inch, an elastic ratio of 50%; and an elongation of 20% in 2 ins. The test piece should be cut at a depth of about 2 ins. from the outside.

Class X.—Hard Forging Steel; for miscellaneous forgings.

Method of Manufacture.—Acid or basic open-hearth process.
Chemical Composition in per cent.—P below .05 in acid steel, below .03 in basic; S below .10; Si below .10; Mn below .90.
Physical requirements as follows:

Shape and Origin of Test Piece.	Ultimate Strength. Pounds per square inch.		Elastic ratio.	Elongation. Per cent.
	Minimum.	Maximum.		
A rolled bar with a cross-section of about 0.5 to 1.0 sq. in., made from a bloom or test ingot. Elongation measured in 8 ins	75 000	100 000	55	12
A $\frac{3}{4}$ in. round, 2 ins. long between shoulders, cut from a rolled or forged piece about 6 ins. in smallest dimension. Elongation measured in 2 ins	75 000	100 000	45	15

The first method will suffice for ordinary work to show the quality of the material. The second involves considerable expense and delay in cutting and finishing the piece, and there is necessarily much variation caused by the different sizes and shapes of forgings. The test pieces should be cut at a depth of about 2 ins. from the outside.

CLASS XI.—Common Soft Steel; for roof trusses and other structures not exposed to shock.

Method of Manufacture.—Acid or basic open-hearth process or converter.

Chemical Composition in per cent.—P below .10; S below .10; Mn below .65.

Physical requirements as follows:

SHAPE.	Thickness in inches.	ULTIMATE STRENGTH. POUNDS PER SQUARE INCH. Minimum.	Maximum.	Elastic ratio.	Elongation in 8 ins. Per cent.	Reduction of area. Per cent.	REMARKS.
Angles....	$\frac{5}{16}$	56 000	64 000	62.0	25.0	45	A $\frac{3}{4}$-in. hole punched in an angle, with its center $1\frac{1}{4}$ ins. from the rolled edge, shall stand drifting to $1\frac{1}{2}$ ins. without fracture.
"	$\frac{3}{8}$ to $\frac{3}{4}$	56 000	64 000	60.5	25.0	43	
"	$\frac{7}{8}$ to 1	55 000	64 000	59.0	25.0	41	
"	$1\frac{1}{8}$ to $1\frac{1}{4}$	54 000	64 000	57.5	25.0	39	
"	$1\frac{3}{8}$ to $1\frac{1}{2}$	53 000	64 000	56.0	25.0	37	
Plates....	$\frac{5}{16}$	59 000	69 000	60.0	19.0	34	On plates under 42 ins. wide, the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the required elongation shall be lowered 1.5%, and the reduction of area 2.0 per cent. On tests cut cross-wise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent. On universal mill plates the allowance for transverse tests shall be 5 000 lbs., 5%, and 15 per cent. Longitudinal strips shall bend through 180° around a pin 1 in. in diameter.
"	$\frac{3}{8}$ to $\frac{3}{4}$	57 000	67 000	58.0	22.0	40	
"	$\frac{7}{8}$ to 1	56 000	66 000	57.0	22.0	40	
"	$1\frac{1}{8}$ to $1\frac{1}{4}$	55 000	65 000	55.0	21.0	38	
"	$1\frac{3}{8}$ to $1\frac{1}{2}$	54 000	64 000	53.0	20.0	36	
"	$1\frac{5}{8}$ to 2	53 000	64 000	51.0	19.0	34	
Eye-bars annealed.	$\frac{3}{4}$	56 000	64 000	56.0			The elongation in full length shall be 12.5% in bars from 10 to 20 ft. long, 12.0% in 21 to 25 ft., 11.5% in 26 to 30 ft., and 11.0% in 31 to 35 ft.
" .	1	56 000	64 000	55.0			
" .	$1\frac{1}{8}$ to $1\frac{1}{4}$	55 000	64 000	53.0			
" .	$1\frac{3}{8}$ to $1\frac{3}{4}$	55 000	64 000	52.0			
" .	2 to $2\frac{1}{2}$	54 000	64 000	51.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

CLASS XII.—Common Hard Structural Steel; a substitute for Class XI when greater strength and less ductility are required.

Method of Manufacture.—Acid or basic open-hearth process or converter.

Chemical Composition in per cent.—P below .10; S below .10; Mn below .85.

Physical requirements as follows:

SHAPE.	Thickness in inches.	ULTIMATE STRENGTH POUNDS PER SQUARE INCH. Minimum.	Maximum.	Elastic ratio.	Elongation in 8 ins Per cent.	Reduction of area. Per cent.	REMARKS.
Angles ...	$\frac{5}{16}$–$\frac{3}{8}$	60 000	68 000	60.0	22.0	40	A $\frac{3}{4}$-in. hole punched in an angle, with its center $1\frac{1}{2}$ ins. from the rolled edge, shall stand drifting to $1\frac{1}{4}$ ins. without fracture.
" ...	$\frac{7}{16}$–$\frac{1}{2}$	60 000	68 000	58.5	22.0	38	
" ...	$\frac{9}{16}$–$\frac{5}{8}$	59 000	68 000	57.0	22.0	36	
" ...	$\frac{11}{16}$–$\frac{3}{4}$	58 000	68 000	55.5	22.0	34	
" ...	$\frac{13}{16}$–$\frac{7}{8}$	57 000	68 000	54.0	22.0	32	
Plates....	$\frac{5}{16}$–$\frac{7}{16}$	63 000	73 000	58.0	17.0	29	On plates under 42 ins. wide, the required elongation shall be raised 1.5%, and the reduction of area 2.0 per cent. On plates over 70 ins. wide, the required elongation shall be lowered 1.5% and the reduction of area 2.0 per cent. On tests cut crosswise from the sheet, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10%. On universal mill plates, the allowance for transverse tests shall be 5 000 lbs., 5% and 15 per cent. Longitudinal strips shall bend through 180° around a pin, the radius of which is $1\frac{1}{2}$ times the thickness of the plate.
"	$\frac{1}{2}$–$\frac{3}{4}$	61 000	71 000	56.0	20.0	35	
"	$\frac{13}{16}$–$\frac{7}{8}$	60 000	70 000	55.0	20.0	35	
"	$\frac{15}{16}$–1	59 000	69 000	53.0	19.0	33	
"	$1\frac{1}{8}$–$1\frac{1}{4}$	58 000	68 000	51.0	18.0	31	
"	$1\frac{3}{8}$–$1\frac{1}{2}$	57 000	68 000	49.0	17.0	29	
Eye-bars annealed.	$\frac{3}{4}$–1	60 000	68 000	55.0	The elongation in full length shall be 11.5% in bars from 10 to 20 ft. long; 11.0% in 21 to 25 ft.; 10.5% in 26 to 30 ft., and 10% in 31 to 35 ft.		
" .	$1\frac{1}{8}$–$1\frac{1}{2}$	60 000	68 000	54.0			
" .	$1\frac{5}{8}$–2	59 000	68 000	52.0			
" .	$2\frac{1}{8}$–$2\frac{1}{2}$	59 000	68 000	51.0			
" .	$2\frac{5}{8}$–3	58 000	68 000	50.0			

SHAPES.—In channels, beams, etc., the requirements on tests cut from the web shall be the same as for plates between 42 and 70 ins. wide, with the same allowance for difference in thickness. In tests cut from the flange, the minimum tensile strength shall be lowered 3 000 lbs., the elongation 3%, and the reduction of area 10 per cent.

STEEL CASTINGS.

Method of Manufacture.—Acid open-hearth process.

Chemical Composition in per cent.—P below .04; S below .05; Mn below .80.

Physical requirements as follows:

Grade.	Shape and origin of test piece.	Condition of test piece.	Ultimate Strength, Pounds Per Square Inch.		Elastic ratio.	Elongation, Per cent.
			Minimum.	Maximum.		
Soft	¾ in. round, 2 ins. between shoulders, cut from a coupon or casting	Annealed	54 000	64 000	50	20
		Natural	57 000	67 000	50	15
	A round or flat test piece, rolled from a small test ingot of the heat from which castings are made. Tested in 8-in. length	Natural	58 000	68 000	55	20
Hard	¾ in. round, 2 ins. between shoulders, cut from a coupon or casting	Annealed	60 000	70 000	50	15
		Natural	63 000	73 000	50	15
	A round or flat test piece, rolled from a small test ingot of the heat from which castings are made. Tested in 8-in. length	Natural	64 000	74 000	55	15

NOTE.—No record shall be kept of test bars exhibiting imperfections.

Recommendations.—It is recommended that the rolled test bar ("preliminary test") be used as a rule, and that the expense of cutting a piece from a casting be resorted to only occasionally as a check. Also, that castings of simple form be used without annealing. Also, when a large number of similar pieces are to be made, that special bending or drop tests be devised, such tests, together with the chemical analysis, to be the sole requirements.

DISCUSSION.

GUS. C. HENNING, Esq.—The proposed specifications have evidently been carefully prepared and systematically arranged, and are admirably drawn, as a rule, to suit the product of the basic open-hearth furnace. Exception should be taken, however, to a number of statements in Mr. Henning.

Mr. Henning. the preliminary paragraphs preceding the classification proper of the different kinds of material.

The author states: "It is certain that the ordinary systems of testing fail entirely to distinguish the product of the open-hearth from that of the Bessemer converter." The speaker believed that the microscopical examination of the structure of specimens may be considered among the ordinary systems of testing and it readily distinguishes the methods by which steel is manufactured. The author states further: "Notwithstanding this fact there is good testimony to show that the product of the converter is an inferior metal, which gives way in a treacherous manner under shock." No data or instances are given to justify this broad statement, and in view of this the speaker stated that he had met with cases of accidental fracture of angles and channels of Bessemer and open-hearth steel which showed invariably that the failure was not due to the steel but to the heat treatment the metal had received, the fractures showing a coarse, crystalline structure such as soaking or overheating will produce.

During the inspection of the shop-work of the superstructure of the East River Bridge, both shapes and rivets failed repeatedly, and the most careful chemical analyses and physical investigations never revealed any differences in composition, while the fractures themselves plainly showed the cause of rupture to be overheating. Also while the shop-work on the Blair and Henderson Bridges was being inspected, similar accidents occurred, which, as before, could not be attributed to the character or quality of the steel, the fractures showing plainly that the materials had been overheated. It must be borne in mind that in these cases, the first being Bessemer and the last open-hearth steel, the trouble occurred in thin shapes only, $\frac{5}{16}$ in. or less in thickness. Examples of even worse failures than these were steel eye-bars which had been tested to destruction, the defective bars invariably showing overheating, caused by the anxiety of the forge gang to earn large wages. They knew that eyes could be formed readily and rapidly by heating the bars to a very high heat, in fact to a temperature which just caused the edges of the bars to melt. This ruined them by overheating, as they all failed in the neck or eyes, showing coarsely crystalline fractures. The speaker had never yet seen a case where failure of any shape steel while being punched was not due to bad furnace treatment, neither had he found recorded any evidence of difference in the character of the material at the point of fracture from that at other points of the same bar. Moreover, as no impact tests comparing Bessemer and open-hearth steel are in existence, the broad statement by the author that "the product of the converter is an inferior metal which gives way in a treacherous manner under shock" is entirely unwarranted.

The author states also that the only safe way to avoid accident is to

use open-hearth steel. The speaker asked whether the propriety of using Bessemer steel for rails had ever been questioned, and further, if there were not several million tons of Bessemer steel rails in use on the more than 150 000 miles of railways in this country, and if these were not subjected to much severer shock than any member of a bridge. Mr. Henning.

The author asserts that copper has no appreciable influence on the strength and ductility of steel, but the speaker said that a large percentage of copper increases materially its ultimate strength and ductility, as wire manufacturers have learned. He also asked for proofs of the author's statement: "For just as it (manganese) resists the separation of the crystals in cooling from a liquid state, so it opposes their formation when a high thermal altitude augments the molecular mobility."

In Table No. 3, a series of tests are given which purport to represent the behavior of steel under shock, but the speaker could not agree with the author that these tests do this. The shock is none such, in the first place, and is applied at right angles to the initial strain. Shock cannot really be produced by a copper hammer, which is purposely made of very soft pliable metal, so as not to apply sudden intense strains to the harder and more elastic material on which it is used. Moreover, shock in order to be effective should be applied in the direction of application of the initial load, in order to show its effect on the metal under investigation.

The author says of phosphorus: "For common structural material, the critical content has been placed by general consent at 0.10%, but this is altogether too high for railroad bridge work." In view of the fact that thus far no bridge has ever failed or given the slightest cause for alarm on account of the phosphorus content of the steel, the speaker held such a statement to be hardly justified. He also considered that the author does not present the facts concerning physical properties in exactly the proper manner. The strength of steel in a $\frac{3}{8}$-in. plate is compared with that of a $\frac{3}{4}$-in. angle, supposing them to be rolled from the same ingot. This he believed to be neither just nor proper. The principal aim of an engineer must be to build a bridge which is constructed of a material uniform in quality, no matter in what shapes it be used. Chords, posts and struts, as well as floor beams and stringers, must be built up of shapes of various dimensions, but as they should work as units the material should be uniform. Angles, channels and plates are never rolled in the same set of rolls. The ingots are rolled and cut into suitable blooms and distributed to various points of a works for finishing. It is, therefore, no hardship or difficulty for a mill to select ingots for shapes according to the finished dimensions, basing such a selection on the preliminary test, which is always a sufficient guide for a competent mill man. There is no reason why an engineer should accept a hetero-

Mr. Henning. geneous lot of stuff, simply because it allows the blooming mill to cut up its product indiscriminately according to the weight of finished pieces. Sometimes, it is true, there will be a quantity of stock left over which cannot be used immediately and must be stored, but as every works office first tries to utilize all stock on hand, having a correct list of quality and size of pieces (blooms), this becomes a simple matter. Now, the rule is that steel made for angles is not used for plates, and *vice versa*, although steel intended for bars and angles is frequently the same, because mill men know that the finished shapes will have very similar qualities. In Europe, where material is tested in its finished shape only, and never in the shape of preliminary ¾-in. rounds, the question of expense has never been raised, and their bridges do not cost as much per pound as American structures. Nor does steel in Europe cost more per pound than here, although always tested in finished shapes. It is quite certain that the steel-maker never bears the expense of testing, for that is always taken into account in making a price.

It did not seem reasonable that material of variable quality should be accepted by engineers because one kind will not show the same qualities in all thicknesses. It seemed much more reasonable that a contractor, knowing the requirements, should arrange for the manufacture of his product in such a way that with intelligent supervision a uniform result will be secured.

An inspector should devote his entire attention to the quality of the finished product, and leave all preliminary tests to the mill men; that is their business alone. Those who know how easily the quality of steel can be modified by careful and proper heat treatment will bear out this statement.

The author attempts to show the influence of the shape of the test piece on results obtained; and to do this he has had ¾-in. rods and 2 x ⅝-in. flats rolled under similar conditions, and then tested. The differences found are then ascribed to shape alone. This did not seem at all proper; these shapes were neither similar in periphery, in scantling, in amount of work done upon the billet, and it is not certain that the finishing temperatures were identical. The differences in the results, however, are so slight that he thought it would be very hazardous to say to what they might be due. Then in comparing these tests with those of similar bars, described as annealed, it seemed certain that all of these bars were too highly heated, and not properly annealed; the results of tests of these bars indicate this very clearly, and hence the accuracy of the statements made, based on them, may be questioned. In a paper by the speaker, published in the *Transactions* of the American Society of Mechanical Engineers, Vol. XIII, p. 572, he showed what effect proper and improper annealing had on structural steel. While proper methods produce beneficial results,

such inferior results as those quoted by the author lead to the belief that these test bars were raised to a very high heat, about to yellow color. The difference between these annealed and natural tests were not thought by the speaker to show differences due to rolling, as is indicated by Table No. 8. The author's tests on relative elongation are very valuable, although they are only corroborative of a vast amount of work done and published. The Committee on Standard Tests of the American Society of Mechanical Engineers has given* a full explanation of this variation of elongation, and a number of papers on the subject are to be found in the publications of various engineering societies. In these various papers it is definitely proved that at the maximum load carried by any test piece the percentage of elongation is absolutely uniform, no matter what length of test piece is used; and that the varying percentage of elongation after rupture is solely due to local distortion at the point of fracture. Hence, if this local elongation be deducted from the total, the remaining elongation will always be proportional to the length of the test piece. Mr. Henning.

The author says that variations in the width of the test piece have little effect upon the reduction of area, but a slight deterioration is indicated with increase of width. The speaker claimed that if greater width had been chosen and tested, the author would have found that width materially affects reduction of area, and that the tests made lie within those limits which do not fairly show this effect.

Exception was also taken to the author's opinion: "A softer metal than is often employed should be used for bridges, because although a slight sacrifice is made in the ultimate strength this is partly offset by the higher elastic ratio and a decided increase in toughness and resistance to shock," which statement, as shown in a paper† on impact tests of steel by Professor Martens, of Berlin, could not be substantiated.

Under "Class I, Dead Soft," the author includes steel for wire cables, but the qualities prescribed by the tests are not those of a satisfactory cable wire. The speaker believed that entirely different tests should be applied to determine the suitability of any steel for wire cable, and said that it is well known that the softest wire is by no means the most suitable for wire cables, but that a hard wire will give much greater service and life. He recommended Mr. J. B. Stone's continuous bending tests. It seemed to him that, inasmuch as all rivet steel is to be subjected to high heat while being formed into rivets and again while driving them in work, an additional test should be prescribed, and this to each and every rod, viz., "to bend one end of each and every rod around a square corner." This will determine whether

* See the *Transactions* of the American Society of Mechanical Engineers, Vol. XIII, p. 289.

† Published in the *Transactions* of the Royal Testing Laboratory at Charlottenburg, Berlin.

Mr. Henning. any rod has been slightly overheated, as such a rod will show cracks while bending, and at the same time the test will cull rods which are split or piped. In half a day a great many tons of rivet rods can be thus tested; hence it will not add materially to the cost.

The principal and only serious objection to be made to these specifications, in his opinion, was the following: That while the steels defined by Classes I to VI and Class IX are made easily and cheaply by the basic open-hearth process, those described in Classes VII to XII, excluding Class IX, cannot be produced with unvarying certainty or uniformity by it; and that, while Classes VII to XII, excluding Class IX, can be made cheaply and uniformly by the acid open-hearth process, the remainder cannot be made easily, regularly and economically by it. The experience had with the open-hearth process is this: That while the acid process is most suitable and economical for steels having a tenacity of 60 000 lbs. or more, the basic process is most reliable and economical in the production of steels having a tenacity of less than 60 000 lbs. The experience on the continent of Europe, where makers are dependent upon low-grade ores, and where steel-making was not economically very successful until the introduction of the basic furnace, is that this process is the cheapest and most reliable for working their materials, but is not uniformly reliable in producing higher carbon steels, and in fact that sufficient experience has not been had with it to produce a uniform quality of such material.

On the other hand, the acid open-hearth process is most serviceable in the production of high-carbon steels, but is not so reliable in producing a steel very low in carbon, adding materially to the cost of production and not producing uniformly satisfactory results, besides requiring increased watchfulness and attention.

Therefore, in these specifications the speaker considered Classes I to VI and IX should preferably be made by the basic process, while VII to XII, excepting Class IX, should be made by the acid open-hearth process. The author's contention that Bessemer steel should be excluded entirely cannot be agreed to, as this would be a great injustice to a number of reputable establishments which have always produced a reliable Bessemer product. The author's assumption that the very soft and weak steels, which he defines, should be used at least as much as stronger steels, may be correct when referring to small structures where increased dead weight does not materially increase the cost; but it does not seem to hold good in the case of a large structure, where the dead weight to be carried is always many times that of the live load, and really determines the cost of the structure. As there is no difficulty in obtaining very strong steels of absolute uniformity, and as many shops are well able to handle such material properly, at a price only a little above that of very low steels, there will be in many cases no justification for the use of the latter. If there were any

scarcity of high-grade materials to produce these high steels, as there is in Europe, there would be reason for discrimination against the latter. As our country, however, furnishes ample supplies of raw materials for all grades of steels, our engineers should always use their discretion in selecting the most suitable material for the particular structure in hand, instead of being guided entirely by the pound price of the steels offered by the makers. Mr. Henning.

FREDERICK H. LEWIS, Esq.—As a part of practical working specifications, it is not likely that the draft in the paper as prepared will commend itself, although for the facts set forth and the many suggestions developed, the paper is undoubtedly a most valuable contribution. Mr. Lewis.

The author seems to have been over liberal in some respects, being willing to grant more in the way of chemical requirements for steel than engineers have previously thought it necessary to ask. For instance, we have been led to believe by metallurgists of high standing that a phosphorus percentage of 0.08 as an average, with a maximum of 0.10, was all that could reasonably be asked for in the regular grade of acid open-hearth steel, and that to tax this product with more stringent requirements would increase the cost so much as to debar it from competition with Bessemer or basic steel. Manufacturers who are making strictly acid steel, and have no basic furnaces to supply low-phosphorus stock, will certainly find it difficult to meet the phosphorus percentages suggested. If the author's phosphorus percentages for acid open-hearth steel are adopted, it is likely to be legislated out of existence.

Again the specifications are open to criticism for giving too great a scope to basic steel. As a soft steel, there can be no doubt that the basic product is a superior metal. But it is found that the low-phosphorus percentages which are such a valuable feature of this product require high figures for carbon. Thus in moderately heavy sections, it is found that an ultimate strength of 60 000 lbs. in basic steel requires generally from 0.23 to 0.25% carbon, and rather frequent failures to stand the quenching test are found in basic steel giving these figures on ladle analysis. It is quite certain that engineers will not give much scope in structural work to a steel which will temper, or, in other words, which fails, in the quenching test. To suggest basic steel with a tensile strength above 64 000 lbs. for structural work does not seem to be well advised, especially when the vagaries of the recarburizing process are considered.

Some facts are developed in the paper in regard to how tests are obtained—the science of producing tests. A great deal more might be said on this subject, but the author has clearly outlined the principles which have been followed in this study. He says in connection with it that inspectors have been a party to these methods to some extent and that this course is creditable to them. This statement is not

Mr. Lewis. likely to pass unchallenged. Clearly an agent who withholds facts or who in any way tampers with them is treading on dangerous ground. In the present case, however, there is one important consideration to justify such action, viz., that an inspector in these cases is dealing with conditions which the specifications do not recognize and with facts which the profession has not admitted and is apparently not yet prepared to admit. Under such circumstances, inspectors probably are justified in assuming their own judgment to be the best guide.

The conditions of tests and the methods of testing are things which engineers can regulate in conference, and there is nothing at the present time more important than a deliverance from the American Society of Civil Engineers on "Standard Methods" for testing steel. The specifications to-day assume (1) that steel is homogeneous, and that it does not make any difference where the test piece or sample is taken; (2) that there is no difference in results in tests from different sections; (3) that there is no difference in tests due to the preparation of test pieces; and (4) that the regimen of the testing machine has no effect on results. None of these assumptions is true or even approximately true.

It is disappointing to find comparatively little in the paper about segregation. The available data on segregation is unfortunately small, but what there is of it shows that 25% increase in carbon and phosphorus may be expected in good practice and occasionally much higher figures. As tests are now made, they are intended to represent the average quality of the metal and in fact generally do represent the better part of it. This is fair enough, no doubt; but as entire melts are accepted for use, it is certainly logical to ascertain what the material is like at its worst. Of what use is it to file results showing a soft ductile material with percentages of elongation in the neighborhood of 30, when it is evident that a test piece selected on a different principle might not show 20% elongation?

The author states that a percentage of 0.12% phosphorus in steel would be criminal. If he means that percentage to be a maximum, then it may be confidently asserted that our structures contain many such crimes.

The preparation of tests and the methods of testing undoubtedly affect results to a considerable extent. The author shows that the greater the width, the greater the stretch in 8 ins., and gives formulas which have been devised by different parties to represent this fact. None of these formulas, however, amount to anything, and a common-sense explanation of this simple fact may not be amiss. It is this: It has been agreed to use an 8-in. length in which to measure the elongation of test pieces. It will be found by examination that in the draw-down adjacent to the fracture the percentage of stretch in soft steel is in the neighborhood of 50, while beyond these curves to the gauge limit on either side the elongation is only about 20 per cent.

Mr. Lewis.

The effect of increased width, then, is simply to increase the length of the curves which constitute the draw-down to the fracture, or in other words to increase the length in which there is a high percentage of elongation. The difference in elongation due to the width of the specimen may be approximately given as follows for the same material:

For width of	1	in.	25	per cent.
" "	2	"	27	"
" "	3	"	30	"
" "	4	"	34	"
" "	5	"	38	"
" "	6	"	42	"

Without submitting detailed evidence on this point, attention is called to Table No. 15, which shows as an average of over 800 tests of full-sized eye-bars that the elongation at the fracture was 35½% in 12 ins. This would be quite 40% in a gauged length of 8 ins. To eliminate this difference in results requires a limit to the width of specimens, and not a limit in area.

The author gives a table showing a difference in elastic limit in the same steel from 39 000 lbs. at a slow testing speed to 46 000 lbs. at a rate of a 4½ ins. fall of pulling-head per minute, this latter being about the standard speed now in use in testing at the rolling mills. Just what view he takes of these figures is not clear, but apparently he regards it as an actual change in the elastic limit of the material. Such a view is certainly not tenable. Mr. Estrada gives some reason to think that the elastic limit is variable under shock, but he gives figures which are lower than was expected. There is nothing whatever to justify a belief that a comparatively small change in the rate of motion of the pulling-head of a testing machine would affect the actual elastic limit of the material in any way, much less to the extent of 15 to 20 per cent. Undoubtedly the lower figures reported give the correct elastic limit of the specimen. The determination of elastic limit by the fall of the beam is based entirely on the idea that when the test piece stretches faster than the fall of the pulling-head, the strain will relax, and the beam fall. At the slow speed which was customary when this method was adopted, the determination of the elastic limit in this way was correct, but it is perfectly clear that when higher rates of speed are used, it is possible to pass directly through the true elastic limit of the specimen and obtain a fall of the beam at some point beyond where the stretch of the specimen becomes greater than the speed of the pulling-head. The fact is that there is no way of determining the elastic limit except by testing slowly. This is quite as true of automatic devices as it is of the determination by the fall of the beam. It is, however, quite impracticable to make mill tests for the reception of structural material, without running testing machines at high speed. If the mills are run for great outputs, the testing machines must keep pace with the product; and as a high testing speed

Mr. Lewis. gives reasonably correct and comparable results for ultimate strength, for elongation and for the character of the fracture, no objection should be made to it, but it should be recognized as a fact that the elastic-limit determinations are not correct and not comparable. Nearly all the figures are considerably inflated for the reasons explained above, but in different degrees depending upon the regimen of machines.

On this matter of elastic limit the paper develops a remarkable difference between the views expressed in the draft of specifications and the facts which were brought forth at the outset to support these views. It will be found in the specifications that the author suggests elastic ratios as low as 47%, but in the record of tests which he submits, no elastic ratio below 62% is found in unannealed specimens. It is a little hard to see how he can justify his low elastic ratios in the specifications in comparison with the high elastic ratios submitted in his data, and he unquestionably owes some explanation on this point. That the specifications are measurably in accord with the real facts the speaker fully believed, but, if so, what then are we to think of the tests quoted?

The following table gives the results of some careful determinations of elastic ratios in soft steel of different thicknesses. These tests were made by the speaker with special care to have the figures correct.

Ultimate Strength.	Elastic Limit.	Thickness.	Elastic Ratio.
Pounds.	Pounds.	Inches.	
54 290	27 280	.805	50.0
58 030	30 950	.663	53.0
60 200	34 600	.559	57.5
61 720	34 270	.550	55.5
58 600	32 780	.505	56.0
55 620	33 290	.427	60.0
62 390	37 340	.375	60.0
59 240	37 870	.365	64.0
62 650	38 875	.315	62.0
60 360	40 890	.265	68.0
57 200	36 060	.225	63.0

In view of the errors in elastic-limit determinations, the speaker favored abandoning these determinations in regular tests made for the reception of steel at the rolling mills and substituting instead occasional determinations in laboratories where facilities can be had for making such determinations accurately.

The absolute requirements of specifications are matters of agreement between the contractor and the purchaser. What is needed today in testing steel is not new tests or more severe tests, but rational methods in testing and a recognition of conditions in the material tested. It has been made perfectly clear to intelligent men within the last few years that under the specifications as they stand, a great deal of testing is done which is purely conventional. Something has been done, perhaps, to improve the quality of steel, but a great deal more to develop the science of getting out tests.

CORRESPONDENCE.

Mr. Wagner.

SAMUEL TOBIAS WAGNER, M. Am. Soc. C. E.—Just how far specifications should go toward giving requirements for the chemical composition of steel is a hard point to decide, and generally what might be called the most severe specifications have gone past what seems to be a reasonable boundary; and, after giving in full the physical requirements, have proceeded to practically cover the chemical composition besides, thus binding the manufacturer in on all sides.

It would seem, at first sight, that the present paper approximates this limit by specifying, besides the phosphorus, maximum limits for sulphur, silicon and manganese, and the advisability of going so much into detail is questioned. For all practical purposes the sulphur is regulated in the process of manufacture, as is clearly set forth in the paper, and for the reasons given in another place, it would seem that both the silicon and manganese could also be omitted in the specifications without practical detriment to the resulting metal. The necessity of specifying the maximum limit of phosphorus is unquestioned, as is also the advisability of not specifying the carbon content.

The writer would like to hear from the author as to whether he considers that a minimum limit of phosphorus should be specified on the grounds that a little is better than none.

The writer's attention was first called in 1883 to the difficulty of obtaining anything like uniform results from a heat of steel which was rolled into greatly varying sections,* and his attention was then drawn to the sliding scale in use at that time by the French navy to overcome this difficulty. It is questionable, however, in view of the amplification required in the specifications for ordinary structural work, whether it is advisable to use such a sliding scale for varying thicknesses, or to leave the matter to the judgment of the inspectors in selecting the tests, as is done at present.

The question of the rate of speed in the testing machine upon the results of the tests has always commanded interest, while never being recognized as of any vital importance. As pointed out in the paper, however, there is a necessity for uniformity of results, and some convenient rate of speed, as high as is consistent with accuracy of results, should be established.

The method of making tension tests in Scotland is to pull the specimen as rapidly as possible, and generally in a lever machine without attempting to measure the elastic limit. In this manner as many as 60 tests have been broken in an hour, including the time necessary to measure the specimens, put them in the machine, take them out and

* See the "Report of the Naval Advisory Board Upon Mild Steel Used in the Construction of the *Dolphin*, *Boston*, *Atlanta* and *Chicago*," 1886.

Mr. Wagner. record the result. While this seems to be much too fast, all tests are made at practically the same speed, and the results are comparable. The care taken in the preparation of the specimen, as far as the finish of the machined surface is concerned, is much less than that given in America.

The advisability of using a steel with an ultimate tensile strength of from 50 000 to 58 000 lbs. per square inch deserves careful consideration, but as a steel, say, from 56 000 to 64 000 lbs., is much stronger and is known to be a good, ductile and satisfactory metal in every particular, it would seem a sacrifice of strength for the sake of very little in return.

The writer thoroughly agrees in confining the use of steel for structural purposes to the product of the open-hearth furnace, whether the lining be acid or basic. His reasons for thus excluding the product of the Bessemer converter are based upon mysterious breaks in angles, plates and beams during treatment in the shops, when the only evidence of inferiority that could be found from the most careful investigation, chemical or physical, was that the metal was of Bessemer origin.

Mr. Lund. George A. Lund, Assoc. M. Am. Soc. C. E.—Nearly all the data and suggestions furnished by this paper seem to apply more particularly to bridge specifications than to steel used for building purposes. A few figures compiled from actual tests, showing the action of steel under a compressive strain, would be of great value. The largest part of the steel used in the construction of tall buildings and framed structures subjected to quiescent loads is employed in the shape of columns and beams. There is to-day, and probably will be, a continually increasing demand for this kind of material. The manufacturer should aim, therefore, to acquire a quality of steel for this purpose that can withstand a compression equal to cast-iron and still be of such toughness as to permit of punching and riveting without affecting in any way its durability and reliability. This would enable the engineer who favors steel-riveted work to compete with those employing cast-iron construction, and would eventually give a vast amount of trade into the manufacturer's hands. Steel for this purpose should have an ultimate strength of 70 000 to 80 000 lbs. per square inch in tension.

There is, also, one other feature that the engineer should not lose sight of. He should aim to secure a steel that can resist corrosion for a long period of years, without serious reduction of area. Most of the steel used in building, when once in place, is entirely covered, so that no opportunity is left for inspection and painting. Just what alloy of steel is the most durable under exposure may be an open question. It is, however, the opinion of many that a steel with a large percentage of carbon is most desirable.

Mr. Hunt.

ALFRED E. HUNT, M. Am. Soc. C. E.—An intelligent specification for structural steel as made to-day should prescribe the mode of manufacture as well as the composition of the metal, as stated in the paper, and the open-hearth method of manufacture of steel is preferable for the best grades of structural steel, although a very large amount of excellent quality Bessemer steel is made annually for structural purposes. Basic open-hearth steel has proved to be as good as that made upon the acid open hearth for many purposes, but it is worth noting that the author, as a manufacturer of basic open-hearth steel, concedes the desirability of requiring a lower percentage of phosphorus in the chemical composition of such material over acid open-hearth steel. The manufacturers of basic open-hearth steel in this country have strenuously opposed this, claiming it to be an unjust discrimination against this material. This, however, is not the fact in the case. Basic open-hearth steel, well made, will show a content of phosphorus below 0.04%, unless special precautions are made to add high-phosphorus materials in the ferro-manganese or other final additions in the manufacture of the metal. Under ordinary conditions, steel made by this process in this country, which contains over 0.04% phosphorus, affords an indication that it has not been well made, and that the basic operation has not been satisfactorily conducted, that the basic slag has not performed its function of carrying out the phosphorus as tri-basic phosphate of lime, as it should do. With acid open-hearth steel, the higher percentage of phosphorus contained is not such an indication that the steel has not been properly made. A large amount of excellent acid open-hearth steel is furnished with a maximum 0.08% phosphorus; but a basic open-hearth steel with 0.05 or 0.06% phosphorus should be regarded with a great deal of suspicion, and the writer would want to know what the conditions were which allowed such a high percentage of phosphorus to be contained in the metal, before accepting it for structural purposes.

For purposes where the metal has to withstand violent impact, he prefers to place a higher unit strain upon the soft bridge steel of Class V, with a tensile strength of 50 000 to 58 000 lbs. per square inch, than upon the hard bridge steel of Class VII of the classification in the paper.

With the phosphorus largely eliminated from the metal as made by the basic open-hearth process, in order to get the tensile strength of hard bridge steel of Class VII, it has been found necessary to recarburize the metal considerably, adding difficulties of non-homogeneity of the recarburizing materials and of not giving as tough and ductile a metal, but of giving one which is much more susceptible and liable to inequalities due to cold rolling or otherwise hardening of the metal.

The writer's experience has confirmed the statements given in the paper as to the inert action of a considerable percentage of copper in

Mr. Hunt. structural steels; a proportion up to nearly 0.25% has not been found to injure the metal materially.

The position taken by the author in his paper regarding the difference between "elastic limit" and "yield point" is hard to understand. Defining the elastic limit in tension tests as the point where the increments of extension are no longer proportionate to the increments of strain, the elastic limit as ordinarily obtained in commercial testing is not accurately determined; and while the author's opinion of the value of the "elastic ratio" as one of the qualities of structural steel may be accepted, it is necessary that one of the terms of this ratio, the elastic limit, should be more accurately obtained than is now ordinarily done in practice.

The results of Table No. 17 show the marked difference which can readily be obtained in determining the elastic limit by varying the speed of the testing machine. This, however, is only one of the considerable number of factors by which the determination of the elastic limit can be and is manipulated by the skilled operators of the testing machines employed by the various steel works in commercial practice.

The statements that the elastic ratio and reduction of area decrease with increasing thickness of test specimens, while the elongation remains the same, are to be accepted as correct.

The writer is quoted as advocating the preliminary tests as a method of accepting or rejecting structural steel, that "it is convenient and that it is the fashion," and that he would recommend the acceptance of steel on preliminary tests, "provided that the finished material comes within 4% of the standard thus obtained." Attention is called to the fact that the paper from which the quotation is made was written five years ago, and that the writer cheerfully accedes that the "fashion" referred to has now been entirely changed. He does not think, however, that the author's position that this provision is a *reductio ad absurdum* is consistent with his making practically the same provisions for steel castings. The leaving out of preliminary tests as a requirement for structural steel has been a wise one, provided a suitable number of other tests of finished material are substituted for them. The preliminary tests should be left to the domain of the manufacturer, granting the engineer the right to do as he wishes in his test of the finished material.

The reasonableness of the stipulations of the author's specifications for a variation and concession in the requirement of tensile strength made for varying thicknesses and widths of section is conceded, but his arguments as to the honesty of the methods described of selection of test specimens in important plate work to meet the requirements of rigid specifications, are questionable. The rigid system of tensile requirements now called for in some instances is a reason for, if not a justification of, the practices and "expedients" which the author

admits are "dangerously near the line of deception" adopted by plate rollers to meet the specifications. The important public developments of the past few years as to methods of testing and obtaining test specimens should teach a lesson to engineers not to make rigid requirements of a kind that tend to demoralize mill employees regarding specifications. Mr. Hunt.

In the specification for rivet steel a further test always found satisfactory should be added, viz., to have the rivet steel to be tested actually made up into rivets and riveted up, the requirement being made that the rivets should cut out tough and strong with a cold chisel. This is a practical test, in most cases easily made, and one which in the writer's experience has often caused rejections of steel which otherwise would have been accepted, it being shown that the metal would not stand the punishment of riveting without becoming crystalline and brittle, even though the requirements of the steel would fall within the specification of Class II of the author's specification.

In Class V of soft bridge steel, the writer would recommend the phosphorus in acid open-hearth steel being a maximum of 0.08% instead of 0.06%, not that 0.06% is not a better requirement for steel than 0.08%, but because of the fact, which is plainly stated by the author, who is a basic as well as an acid open-hearth steel manufacturer, that "it must not be forgotten that it cost more to make pure metal by the acid than by the basic process," and that there is a large amount of good structural steel that would be excluded by the maximum requirement of 0.06% in acid open-hearth steel. This requirement of 0.06% phosphorus would be practically handicapping the acid open-hearth manufacturers in their competitive work with the basic open-hearth manufacturers.

On the other hand, if the requirement for sulphur were made, he would suggest a lower maximum than 0.1 per cent. A maximum of 0.06% of sulphur would be better.

A. C. Cunningham, M. Am. Soc. C. E.—The statement that different kinds of steel cannot be told the one from the other by analysis is doubtless true when all have the same chemical composition, but when the analyses and physical properties are considered collectively, one kind can be told from another in the majority of cases. In the case of an attempted fraud to substitute one kind of steel for another, the first consideration must be the securing of the specified physical properties in a specimen tension test, and where these correspond for the different kinds of steel, the nature of the different processes causes a variation in the chemical composition which would be detected by a practical observer. Should the fraud be carried so far as to secure a correspondence of chemical as well as physical results, it would defeat its own end in the increased cost. Mr. Cunningham.

The accidental mixture of different kinds of steel is readily told

Mr. Cunningham. from a consideration of the chemical and physical properties. The plea that engineers should enforce their specifications as to kind and quality of steel specified cannot be urged too strongly. Vacillation and caprice in this respect have a most serious moral effect upon the entire subsequent work; the honest competitor gives some serious study to his motto, "Honesty is the best policy," and wonders if he will have to turn it to the wall; the "concession hunter" is sorry he did not ask for more, and resolves to have it all his own way the next time, and the inspector sees the few weapons that he had for the protection of his principal taken from his hands, for while the kind of steel specified has been changed, nothing else in the specification has, and everything becomes discordant.

In addition to the serious moral effect in conceding a cheaper for a more expensive steel after a contract is let, an actual increased profit is likely to accrue to the contractor, the legitimacy of which is questionable. An engineer would resent it as an insult if asked to change his plans. Is it any less an insult to be asked to change his steel?

In the matter of sulphur the author has been rather too liberal. He recognizes the importance of low sulphur in rivets, but has overlooked the fact that eye-bars are also subject to several reheatings in the course of manufacture, and that the sulphur is of as much importance in the eye-bar as in the rivet.

Steel may be considered as having two sulphur limits, the safe limit, which concerns the engineer, and the economical limit, which concerns the manufacturer; beyond the economical limit of sulphur the loss in rolling more than counterbalances the cheapness of the original stock, and an occasional experience keeps the manufacturer within the economical limit.

From some experiences of the writer he believes that near the economical limit there is a dangerous point for sulphur which may lead to serious results. If the sulphur is sufficiently high to make the material break up in rolling, that is the end of it; but if it is at a point that will just permit the material to finish without visible flaws, it may still be appreciably injured for use.

The wording of the fifth clause under general provisions might cause complications in some instances. Should an engineer decide to have his analysis from the finished material, it is possible that no preliminary analysis would be made, and in the case of Classes XI and XII he might find himself forced to accept steel having 0.15 phosphorus and 0.15 sulphur, or at the best be put to considerable trouble and expense to reject it. This is an extreme case, but it is the extreme cases that cause difficulties.

Mr. Waddell. J. A. L. WADDELL, M. Am. Soc. C. E.—Such papers as this are of the greatest importance to all bridge engineers, more especially to

Mr. Waddell.

those who have no connection with shops, for the reason that they have to base most of the requirements of their specifications in respect to structural steel upon information which comes to them at second hand. As the manufacture of steel is still in the process of evolution, the consulting bridge engineer has to be changing his specifications continually. It is no exaggeration to state that during the last seven years the writer has made no two sets of specifications alike: starting in with the manufacturers' standard specifications as a basis, he has altered, amended, added to and erased from these, until the latest set, that for the Northwestern Elevated Railroad of Chicago, bears hardly any resemblance to the original. Unfortunately the end is not yet, for recent improvements in the manufacture of basic open-hearth steel, and probably future improvements also, will cause the process of evolution just mentioned to be continued for an indefinite time. "Unfortunately" is used perhaps unadvisedly, because substantial improvement is never to be deplored, although systemization of specifications is a great desideratum.

If the principles enunciated in the paper be accepted without modification, all of the existing specifications for structural steel will have to be changed, in order to bring them up to date. It may be well, however, to await a thorough discussion of the paper by those interested in the subject, more especially engineers who are making a specialty of inspecting structural steel, before instituting any changes in what may be termed "temporarily established methods of manufacture and inspection."

For many years the writer has maintained, against bitter opposition, that Bessemer steel is not a fit material for the manufacture of bridges, notwithstanding which he was forced to accept it in the case of one important structure. This opposition to the Bessemer product is shown by the following extract from his latest specifications, which clause has appeared in a slightly different form in all of his superstructure specifications written during the last three or four years:

"All steel shall be manufactured by either the acid or the basic open-hearth process, preference being given to the former, and must be uniform in character for each specified kind. Any attempt to substitute Bessemer or any other steel for the open-hearth product will be considered as a violation of the contract, and a good and sufficient reason for canceling the same."

This clause has been criticized by contractors as being too peremptory and aggressive; but, so far as known, it has had the desired effect, for no attempt has apparently been made to substitute the Bessemer product on any of his work, although this may have been done without his knowledge, as he has often been informed that certain manufacturers make a practice of using metal inferior to that called for by the specifications or manufactured by a process prohibited therein. In this respect a chief engineer is at the mercy of his inspecting bureau

Mr. Waddell. if he employs one, and the managements of such bureaus too often relegate the inspection of important work to inexperienced and careless boys who pass anything and everything regardless of the instructions of the chief engineer.

The writer's limits for phosphorus have been 0.08% for acid steel, and 0.05% for basic, but it appears from the paper that he has been erring slightly on the wrong side, so it will probably behoove him to change. He did once specify 0.03% for basic steel, but it raised such a commotion among the bidders that he had to raise the limit to 0.05 per cent. It appears that the leading manufacturers of basic steel nearly always produce a metal containing less than 0.03% of phosphorus, but they object strenuously to being compelled to furnish it, on the plea that, in spite of all their efforts, an occasional output may contain as high as 0.05%, and they do not want the same to be rejected.

Since writing the clause just quoted from the specifications for the Northwestern Elevated Railroad, sufficient evidence has been presented to warrant the conclusion that basic open-hearth steel is fully as good and reliable as is the product of the acid open-hearth furnace. It seems though, that the use of the basic product tends toward the adoption of softer steel for bridge work. Whether this is advantageous or otherwise appears to be a mooted point. It has been the writer's custom to specify what he termed "medium steel" of an ultimate strength from 60 000 to 68 000 lbs. for all bridge members, excepting adjustable members, and rivets, for which he has used what he termed "soft steel," having an ultimate resistance between the limits of 53 000 and 61 000 lbs. The author would term these steels respectively "hard bridge steel" and "hard bridge rivet steel."

The writer would ask the author and other experts in structural steel whether, considering the latest developments in the manufacture of the basic open-hearth product, which he now recognizes as the coming metal for bridges, he is making a mistake in continuing to use so high a steel; and, if so, why and wherefore? Is there really an element of danger in employing such metal, or is the true reason for reducing the ultimate strength one of economy, caused either by a cheaper product or by the omission of reaming of rivet holes? If the last-mentioned cause be the only one, he will most decidedly make no change, because he maintains that in all the shops with which he is acquainted, the subpunching and the reaming of rivet holes are a necessity, if the holes are to match properly. If the cause be only a cheapening of the process of manufacture, it will be simply a question of economy as to whether to use a certain weight of medium steel at a certain pound price, or a greater weight of soft steel at a lower pound price. But if the question be one of safety or precaution, it cannot be ignored. In times past nobody appeared to object to using steel of an ultimate strength between 60 000 and 68 000 lbs., but such steel was manufac-

tured by the acid open-hearth process. In changing from acid to basic steel, he has not done so without consultation as to whether it is best to change also to soft steel, and thus far he has seen no reason for abandoning the medium steel used for a number of years. Mr. Waddell.

There are some other questions which he would like to ask the author, viz.: 1. What class of steel does he recommend for shop rivets for bridge work? 2. What class for field rivets for same? 3. In respect to reduction of ultimate strength for full-sized eye-bars, would he make the said reduction entirely a function of the thickness, or would he consider also the sectional area and perhaps also the length of the bar? The writer's practice has been to consider the area only, allowing a minimum strength of 60 000 lbs. for bars of 8 sq. ins. area and under, and 56 000 lbs. for those of 20 sq. ins. or over; bars with areas between these limits to have proportionate strength. The question is whether, for example, the limit should be the same for a bar 1½ x 4 ins. x 20 ft. as for one 1½ x 12 ins. x 40 ft. As far as his own practice is concerned, it does not matter much whether the function be one of thickness or one of area, because his limits of ratio of depth to thickness of bars are well restricted.

Some manufacturers have complained of the writer's limits for ultimate strength of full-size eye-bars as compared with those for test pieces of the material; but he finds that they can comply with both requirements by holding up the strength of test pieces for eye-bar metal towards the superior limit. Of course, it would be absurd to expect to obtain an ultimate strength of 60 000 lbs. for an eye-bar of 8 sq. ins. cross-section, if the strength of the metal used in its manufacture ran as low as 60 000 lbs. for small test bars.

In respect to elongation in 8 ins. for test pieces, it has been his custom of late to specify that the percentage shall not be less than 1 500 000, divided by the ultimate tensile strength. Using the higher limit of the latter, this method will give results agreeing very closely with the average minimum limits set in the paper. Similarly in respect to reduction of area, his custom lately has been to place the minimum limit at 3 000 000 divided by the ultimate strength. This also agrees fairly well with the average limits set in the paper.

It is undoubtedly more scientific to vary the elongation and reduction of area with the thickness of the metal and the shape of the section from which it was cut; and he is ready at any time to make the change in his specifications, provided that the consensus of opinion of those interested in the question be in favor of the change. It is unlikely that such a change can be made without considerable remonstrance from inspectors, on account of the extra trouble involved thereby to them. There should, however, be but little opposition developed on the part of the manufacturers, because the result of the change would be favorable to them rather than the contrary.

Mr. Webster. WILLIAM R. WEBSTER, Esq.—Justice cannot be done to the author's valuable paper in the short time available for discussion, but attention is drawn to the full series of papers on the physics of steel which was read at the International Engineering Congress, held in Chicago in August, 1893. This series will come up for discussion at the next meeting of the American Institute of Mining Engineers, and the writer hopes before that time to complete the tests and investigations on which to base a more searching criticism than that now presented.

Any one on reading the paper will be impressed with the great importance of putting into practical everyday use some good machine for testing material under shock; there are several impact machines in use for cast-iron, but not for steel, except those for drop tests of rails and axles. In 1879 Mr. William Kent suggested a good machine for tests of this kind, but the funds have never been found to build and run it.* Another promising machine is that of Mr. E. D. Estrada, which he described, with results obtained, in a paper before the Engineers' Society of Western Pennsylvania.†

If the author's remarks on the "tricks of the trade" are considered in connection with Dr. Charles B. Dudley's recent statements ‡ on the same subject, showing how it would be possible to vary the results of the tension test of pieces cut from the same plate or shape, and if they are used as a plea for a standard method of testing and wider limits to the specifications, they are all right; but to take them as they stand, the natural inference is that such methods are in daily use at the plate and shape mills, and that if such is the case, others may also be in use that have not been touched upon. This is not just to the mills or to the gentlemen who made these statements, as neither of them speak from actual experience.

Over 10 years ago, the chief engineer of one of our largest railroads in giving the writer instructions about his work, said:

"I want thorough tests and inspection made of the material and workmanship, and full reports made on same in order that we will, in the first place, secure good bridges, and, in the second place, that if one of our bridges should fail from derailed train or other cause, we could go before a jury and show by our test reports, etc., that we had put the best material in the structure, and used every precaution to guard against defective material or defective workmanship."

This made a great impression on the writer at the time, and to-day he considers it has even more force, owing to the general use of steel. Suppose one of these bridges should fail, with great loss of life; the case comes before a jury, and all test reports, etc., are produced; what weight will they have before that jury or any one else if such statements as Dr. Dudley's and the author's could be produced from the transactions of the leading engineering societies of the country and

*See the *Transactions* of the American Institute of Mining Engineers, Vol. VIII, p. 76.

†See the *Proceedings* of the Engineers' Society of Western Pennsylvania, June, 1893.

‡See the *Transactions* of the American Institute of Mining Engineers, Vol. XXI, p. 391.

be shown to have been uncontradicted or not proved great exaggera- Mr. Webster.
tions?

The author, in his former paper * on "The Open-Hearth Process," referred to Bessemer and basic Bessemer steel as follows:

"In the field of structural work, as in other branches, the Bessemer converter is always a colossal rival. In the United States, Bessemer linings are almost universally acid, and, therefore, in the following detailed comparison of the two processes it will be unnecessary to consider the metallurgical position of the basic converter or the applicability of its products to the stringent demands of modern engineering."

In the present paper he refers to it as follows:

"It is acknowledged that the case is not yet closed, but until these statements are controverted by direct and positive evidence, the only safe way for the engineer is to prescribe that only open-hearth metal shall be used in all structures like railroad bridges, where the metal is under constant shock, and where life and death are in the balance. And it should be emphasized that if this provision is incorporated, a careful watch should be kept for fraud, as there is no way in which a substitute can be detected. The objections to Bessemer steel are many times emphasized in the production of the basic converter, for at the end of the operation there is often a very considerable percentage of phosphorus that passes back from slag to metal, and which is not always uniformly distributed. This fact utterly condemns it for he best of work."

We have on the other side of the question no less authority than C. Weyrich, Government Architect in Hamburg, Germany, whose paper on the subject will be found in the *Transactions* of this Society, Vol. XXX, page 219. His paper shows that basic Bessemer steel is not such a poor material after all, and that the author, without any experience whatever with the material, is a little premature in condemning it.

The paper states on page 312:

"It is a well-known fact that a mass of steel is never absolutely homogeneous owing to certain liquation phenomena known as segregation, and it is reasonable to suppose that this action will take place to a greater extent in a large mass of metal than in a small one. It is usually assumed that plates which have been rolled from ingots of a large size will show greater variations than those from more usual sections. Paradoxical as it may seem this is not always true, for in the preliminary roughing down or slabbing of the ingot, the top which is the most segregated portion is cut off as scrap. The upper third of the ingot will even than show some segregation in the interior, but Table No. 4 will show that it is of little practical importance."

In nearly all specifications for bridge work, a heat or flow of steel is made the unit, and it is the greatest importance to know just how much variation chemically, or physically, there is to be expected, and how to reduce the same to a minimum. Mr. Henry D. Hibbard

* See the *Transactions* of the American Institute of Mining Engineers, Vol. XXII, p. 349.

Mr. Webster. recently suggested before the American Institute of Mining Engineers the following precautions :

"To guard against segregation in ingots, the following precautions may be observed :

"*First.*—Cast ingots of the smallest practicable size.

"*Second.*—Cast ingots of as cold steel as practicable.

"*Third.*—Cast ingots as slowly as practicable.

"*Fourth.*—If the ingots must be large, and segregation is very objectionable, then purer stock than is otherwise needed must be used, or allowance made to cut off from the top or out of the center enough steel to remove the parts containing the worst segregation.

"*Fifth.*—The method above mentioned, of making what I have called incipient rising steel, must, it would seem, give ingots free from segregation. The steel in the mould is constantly in motion until the moment of solidification, and the impurities have no opportunity to collect anywhere. This method being applicable to soft steel only, however, will give no assistance in overcoming segregation in large high-quality hard-steel ingots."

At the same meeting Mr. Joseph Hartshorne said :

"After struggling with the problem of segregation for more than 15 years, I am in about the same state of mind as I was in the beginning. I do not yet know of any method of preventing it. It can be modified, and perhaps, minimized, by casting slowly, by using small ingots, by keeping the casting temperature as low as possible, etc.; but every now and then, in spite of all precautions, it will occur to a disastrous degree and can never be wholly prevented. The most homogeneous metal in appearance will show signs of it if carefully investigated. At least, I have never yet failed to find signs of this trouble, when I have looked for it carefully. I have been forced to the conclusion, therefore, that segregation cannot be prevented. In many instances it does not occur to an extent that makes much difference, and for many purposes it can be disregarded, but there is always the chance of the one time when it may take place with fatal results. The only solution yet presented of this problem, which is at all satisfactory to my mind, is that the impurities shall be kept so small in amount that segregation, if it does occur, will do no harm. In fact, I begin to fear that this will prove to be the final solution. Of course, I am speaking now of high-quality steel only.

"I agree with Mr. Hibbard in thinking that the hard spots which occur in steel may often be attributed to a local segregation. The usual explanation, that is, badly mixed or unmelted recarburizers, is inapplicable in so many cases that some other cause must be found. This one appears to me to be, at least, very plausible. I think it might be well to repeat here what I have before rather strenuously insisted upon, that the casting temperature of steel has a very decided effect upon the physical characteristics of the metal when cold, and that this effect is carried through to the finished product. Of course, I do not claim any originality for this remark, but it seems to me to be a point that is often overlooked, and it is one that has been denied."

In this same connection we have Mr. A. C. Cunningham's article on "An Instructive Eye-Bar Test," read before this Society March 21st, 1894, and published in Vol. XXXI of its *Transactions*. The writer would call attention to pages 416 and 417 of the article, to Mr. Robert's

discussion on page 418, Mr. Metcalf's on page 426, and Mr. Cunningham's reply on page 435, where this subject is also taken up. Mr. Webster.

But to the engineer it is of the greatest importance to know how the steel-maker decides on the proper amount to cut off the ingot, and also what use is made of the piece cut off. The writer's attention was called recently to an open-hearth steel boiler plate which failed in the shop, and upon an analysis being made the carbon was found to be about 100% higher at the point of fracture than in any other portion of the plate. When the steel-maker's attention was called to the matter he said that they "had not cut off enough from the top of the ingot." It is very fortunate that the plate failed in the shop and not in service.

In 1893 the Baldwin Locomotive Works issued specifications for steel boiler and fire-box plates, in which they only specified maximum limits of phosphorus for each grade of steel, leaving the other elements to the judgment of the steel-maker, but this did not give satisfactory results, and in January, 1895, they issued the following specification, which, as it has a carbon limit of 0.15 to 0.25%, is given here.

Specification for Steel Boiler and Fire-Box Plates.

"All plates must be rolled from steel manufactured by the open-hearth process, and must conform to the following chemical analysis, same being predicated on the use of Dr. Dudley's published methods of steel analyses:

	Boiler Steel.	Furnace Steel.
Carbon, between.....	0.15 and 0.25%.	0.15 and 0.25%.
Phosphorus, not over....	0.05%.	0.03%.
Manganese, not over.....	0.45%.	0.45%.
Silicon, not over.....	0.03%.	0.03%.
Sulphur, not over.....	0.05%.	0.035%.

"A careful examination will be made of every plate, and none will be accepted that show mechanical defects. Any accepted plate that develops defects in working will be rejected.

"A test piece from each plate rolled, taken lengthwise of the plate, and without annealing, should have an ultimate tensile strength of 60 000 lbs. per square inch, and an elongation of 25% in section originally 8 ins. long. The shape of test section to be as shown by sketch at beginning of this specification, all tests being made upon sections having, as near as practicable, $\frac{1}{2}$ sq. in. of area.

"No plate will be accepted if its test piece shows an ultimate tensile strength of less than 55 000 lbs. or greater than 65 000 lbs. per square inch, or if the elongations fall below 20 per cent. The steel is to show the foregoing results when test machine is run at the rate of 1 in. in 3 minutes."

The following notes were sent to the writer by Mr. H. V. Wille, and explain the reasons leading to the adoption of the new specifications:

"Referring to carbon, Mr. Campbell states 'that no other element can confer a given increase in strength with as little diminution in ductility and as little increase in brittleness under shock. It is, there-

Mr. Webster.

fore, absurd to place any limit to the carbon content in a steel of given ultimate strength.' No one can take exception to the premises of this statement, but the conclusions are not at all warranted. All engineers recognize the value of carbon as a hardener, and do not regard it as an 'impurity,' as is evidenced by the fact that a minimum as well as a maximum limit is generally specified.

"For a long time we bought steel upon specifications limiting only phosphorus, and for reasons similar to those advanced by Mr. Campbell, but in the light of the experience gained during that time, we found it absolutely necessary to limit the carbon, for this is the only manner by which we can exercise a check on the heat treatment of a plate, guarding against it being rolled either too hot or too cold, in order to produce a certain specified tensile strength, and there are few mills that would hesitate to use either of these expedients should their preliminary tests prove them necessary.

"Mr. Henry M. Howe, in a paper on the "Heat Treatment of Steel," states that in soft steels the influence of carbon is at times completely masked by the effect of improper rolling; and one is safe in predicting that within the next few years we will witness a reaction against the present laxity in enforcing a carbon specification, and instead of making no provisions at all for this metalloid, specifications will be made more and more severe, perhaps based upon a sliding scale, making provisions for the presence of other elements, and for the gauge to which the steel is rolled.

"That these conclusions were not reached hastily, but after careful consideration of the whole problem, I quote a few tests bearing on this subject:

TABLE SHOWING EFFECTS OF COLD ROLLING.—A HALF-INCH SHEET.

	Section.	Tensile strength.	Elongation.	Analysis.
	Square inches			
Original test	2	57 255	37%	C, 0.13
Test made after rupture	2	58 130	33%	Mn., 0.46
Tests made after rupture, and sheet heated cherry red and allowed to cool	2	51 160	47 5%	Phos., 0.044 Sul., 0 015 Si, 0.019

"We here have a sheet of cold rolled steel which failed at the first opportunity presented, notwithstanding that the adjoining sheet with 0.19 carbon had a tensile strength 10 000 lower.

"Test No. 131.41, in the accompanying table, cracked upon being bolted on the boiler, and was not heated in our works. A 0.30 carbon steel rolled to ½-in. plate should pull higher than 59 000 lbs. Insufficient work was probably put upon this plate, and it was finished at too high a temperature; and I finally quote in the same table in plate No. E412, a test showing a bad case of segregation. It is well known that all the metalloids, including carbon, are apt to segregate in the top of the ingot. By limiting the carbon we compel the mills to discard, in a measure, a certain percentage of their ingots, for they cannot tell from what part of the plate we are liable to take drillings, and any failure of steel not only entails considerable expense to the mill, but also tends to throw some discredit on their product."

TABLE SHOWING EFFECTS OF INSUFFICIENT WORK AND OF SEGREGATION. Mr. Webster.

Test No.	Ultimate strength. Pounds per square inch.	Elongation in 8 ins. Percentage.	Analysis C.	Mn.	P.	S.	Remarks.
131.41	59 100	29.12	0.30	0.46	0.009	0.022	Drillings from crack.
"	61 020	28.75	0.32	0.37	0.009	0.022	" " sheet.
E 412	52 610	25.25	0.18	0.44	0.017	0.014	Original.
"	64 210	16.62	.....	.....	.....	.....	Olsen.
"	54 940	28.75	.....	.....	.....	.....	Mill.
"	65 450	5.00	.....	.....	.....	.....	Punched from plate.
"	61 080	4.12	0.33	0.50	0.056	0.033	Drilled from plate.

The writer considers the author's high limit of .10% for sulphur in Classes V, VI, VII, VIII, IX, and X entirely too high, and especially so for the eye-bar material in Classes V, VI, VII, and VIII, and other forgings in Classes IX and X. The eye-bars are the most important forgings in a bridge, and it would be the worst kind of policy to put material in them containing twice as much sulphur as would be considered safe to allow in rivets in Classes II, III, and IV. It is not clear from the author's specifications just what tests are to be made on eye-bar material at the mill; his full-size tests are very complete, but we need some better system of testing the material at the mill than that now in use, for it is not an uncommon thing to have an eye-bar break in full-size test in the body of the bar away from the portion heated in making the heads, with little or no reduction of area and poor stretch. Failures of this kind have occurred in open-hearth steel as well as Bessemer steel. The steel-maker claims that his material is all right, but that it was spoiled in the annealing, while the manufacturer, on the other hand, claims that his method of working is all right. The analysis, in some cases, will not show the cause of the trouble. It is, no doubt, due in some cases to the bars being rolled on a light mill and finished at too high a temperature. This trouble not always being removed by the ordinary annealing, the writer would strongly advocate more rigid requirements and tests for the eye-bar material than have yet been proposed. He does not agree with the author in any of the following recommendations, to "use a small test ingot rolled into test bar to save expenses of cutting test bar from forgings, or to use similar tests for castings, and to use castings of simple form without annealing." All castings should be annealed and tests made on all materials as used and not in an improved condition due to rolling or forging to smaller size. The matter of expense does not enter into the case, as it can be provided for when the contract is taken. The Baldwin Locomotive Works have been through this matter, and their experience may be of interest. The following is from the writer's remarks in the discussion on "The Physics of Steel" before the American Institute of Mining Engineers:

Mr. Webster. "The experiments of Mr. Howe on the heat treatment of steel are of the greatest value, and throw much light on the changes which occur in the structure of the metal. I trust that such experiments will be continued on a larger scale, in connection with the work of rolling or forging at different temperatures. A test report received from Mr. S. M. Vauclain, superintendent of the Baldwin Locomotive Works, gives the result of tests made upon two 8½-in. steel blooms, furnished to the works to be forged into axles. They had been bought on a specification calling for a certain tensile strength and elongation in a test specimen cut from the blooms and drawn down under the hammer to 1 in. square. Some large driving axles, forged from such blooms, having failed to meet the physical requirements of the purchaser, although the test specimens had met the requirements of the specification, and although such failure had never been experienced before, even with forgings from 6½-in. blooms, it was suggested that the cause of the failure might be that the particular blooms from which the axle had been forged had received little or no work in the mill; in other words, had been rolled from small ingots instead of large ones. In order to ascertain the effect of extra working, two sample blooms were forged from 8½ down to 7, 6, 5 and 4 ins. successively, and test specimens were taken at each stage. It was found that the successive forgings materially enhanced the value of the steel. The elongations increased as the size was diminished by forging. It was noticed, however, that in the first bloom there was a slight decrease, and in the second a considerable increase of tensile strength. This phenomenon is attributed by Mr. Vauclain to the circumstance that the second bloom had been allowed to retain its original size at the bottom of the ingot. On the result of this experiment, Messrs. Burnham, Williams & Company, of the Baldwin Locomotive Works, changed their specifications so as to require that the test-piece should be cut from the bloom furnished.

"The small elongation and crystalline fractures of the larger sizes covered by this report show clearly, I think, the trouble caused by improper heat treatment, while the greatly superior results in the smaller sizes indicate the true value of the material. By annealing the larger pieces, the stretch and fracture might be made, no doubt, equal to those of the smaller pieces in their present state, but it is only by careful experiment that the best methods of working can be established."

The results given by the author, in Table No. 13, showing the influence upon the elongation of a change of length of the test-piece, and in Table No. 14, on other physical properties are misleading, as the pulling speed of the machine was the same in all cases, which gives pulling speed on a 2-in. piece, and a 14-in. piece as 7 to 1; therefore, the results are not due to difference in lengths alone, but partially to difference in pulling speeds, as shown by Table No. 17. The ordinary allowance in plate-mill testing is 5% increase in tensile strength in 2-in. boiler test over the ordinary 8-in. test, the pulling speed of the machine being the same, that is, the 2-in. piece being pulled four times as fast as the 8-in. piece.

The author's conclusions, as regards universal plates, are based on tests made on material cut from the edges of the plates. Such pieces

give lower ultimate strength, lower elastic limit, with more reduction and more stretch than pieces cut from the center of plates; the cross-bends of universal plates are not as good as the longitudinal bends. Before accepting his additional requirements for material of this kind above those for sheared plates, we should have a very complete series of tests covering the points raised, and then if the requirements are accepted, limit the width, so covered, to 36 ins. and under, as there is only one mill in the country than can roll universal bridge plates up to 42 ins. in width. Mr. Webster.

The writer considers the elastic limits and elastic ratios given in the paper too high and very misleading. The author appreciates this, no doubt, for after giving in his tables elastic ratios of 72.9, 70, 73, etc., on material ¾ in. thick, as though they were of every-day occurrence, in his specification he has only two cases in which he calls for 60% elastic ratio in plates ¾ in. thick, and four in which 60% is called for in angles ¾ in. thick, and in no case is 60% called for in material over ¾ in. thick. But assuming that these specifications are all right as to elastic limits specified, then what practical value is there in asking for angles with 63% elastic ratio, and making a chord section by riveting these angles to plates with only 49% elastic ratio? The strength of the member would depend on the 49% elastic ratio, which is very close to the old idea of "elastic limit of not less than one-half the ultimate strength."

Assuming on the other hand that the elastic limits and elastic ratios as given in the tables are all right, and not questioning the author's results or methods of testing, the writer endeavors to find out what they show, and whether the author's conclusions are justified in any way by the results as given in these tables.

Table No. 8 shows that the elastic ratio of Bessemer steel is 3.04% higher than that of basic open-hearth steel of same ultimate strength as given below:

Bessemer.		Open-Hearth.	Difference.	Bessemer.		Open-Hearth.	Difference.
Rounds.....	71.88	68.81	3.07	Flats.....	71.33	69.51	1.82
"	73.00	68.51	4.49	"	70.92	68.36	2.56
"	71 34	69.47	1.87	"	70.31	64.96	5.36
"	69.42	66.71	2.71	"	67.93	65.50	2.43
Average difference.....			3.04	Average difference.....			3.04

Table No. 11 shows that the elastic ratio of Bessemer steel is 3.52% higher than that of acid open-hearth steel with same phosphorus content, and 4.10% higher than acid open-hearth steel with

Mr. Webster. from 0.02% to 0.03% lower phosphorus content, the materials compared having same ultimate strengths in each group as given below:

Ultimate strength Pounds per square inch.	Thickness of angles in inches.	Acid Bessemer. P. 0.07 to 0.10.	Acid open-hearth. P 0.0 to 0.10.	Difference.	Acid open hearth. P. 0.05 to 0.07.	Difference.
56 000 to 64 000.....	$\frac{5}{16}$ to $\frac{3}{8}$	71.58	68 50	3.08	67.72	3.86
	$\frac{7}{16}$ to $\frac{1}{2}$	71.00	66.30	4.70	65.66	5.34
	$\frac{9}{16}$ to $\frac{5}{8}$	69.11	64.96	4.15	64.50	4.61
	$\frac{11}{16}$ to $\frac{3}{4}$	66.70	64.15	2.55	63.63	3.07
64 000 to 72 000.....	$\frac{5}{16}$ to $\frac{3}{8}$	70.09	67.02	3.07	66.15	3.94
	$\frac{7}{16}$ to $\frac{1}{2}$	68.66	65.06	3 60	64.87	3.79
Average difference ...	.....	.....	.....	3 52	.....	4.10

Table No. 16 gives the following differences in the elastic ratio in sheared plates corresponding to different widths of test pieces.

Test piece $\frac{1}{2}$ in. wide has 65.58% elastic ratio.

" $\frac{3}{4}$ " " 63.00 " "

" 1 " " 62.29 " "

" $1\frac{1}{2}$ " " 62.11 " "

" 2 " " 62.18 " "

Now, in order to keep the area of the test pieces down to $\frac{1}{2}$ sq. in., the following widths would have to be used for test pieces cut from plates $\frac{5}{16}$ in. to $1\frac{1}{4}$ in. thick. The differences in elastic ratio due to these widths of test pieces are given below.

Thickness.	Width.	Elastic ratio from above.
$\frac{5}{16}$ in.	1.59 in.	62%
$\frac{3}{8}$ "	1.33 "	62%
$\frac{1}{2}$ "	1.00 "	62%
$\frac{3}{4}$ "	0.66 "	63%
$1\frac{1}{4}$ "	0.40 "	66%

That is an increase of 4% in the elastic ratio for the $1\frac{1}{4}$-in. plate, but the allowance in the different classes of material, V, VI, VII, VIII, IX, XI and XII, is a decrease of 9%, or just the other way. Is this in spite of the difference due to narrow test piece? If such is the case, the proper allowance for test pieces $1\frac{1}{2}$ ins. wide would be 13% between $\frac{5}{16}$-in. plates and those $1\frac{1}{4}$ ins. thick.

Table No. 17 gives the following differences in ultimate strength, elastic limits and elastic ratios due to differences in pulling speed. From this table it will be noticed that there is a difference in ultimate strength of 2 048 lbs., a difference in elastic limit of 6 061, and a difference in elastic ratio of 7.51 per cent. This would have been much

more complete had the author stated which of these results he considered the true elastic limit. Mr. Webster.

In ordinary testing, different combinations of the above speeds are used as follows:

Pulling speed. Inches per minute.	Ultimate strength. Pounds per square inch.	Pulling speed. Inches per minute.	Elastic limit.	Elastic ratio.
4.50	61 075	0.07	39 647	64.9
4.50	61 075	0.38	41 763	68.2
4.50	61 075	0.67	42 904	70.2
4.50	61 075	3.00	44 410	72.7

That is, with the same ultimate strength a difference of 4 768 lbs. can be obtained in the elastic limit and 7 8% in the elastic ratio, by using different pulling speeds. Applying these results to Bessemer and open-hearth steel plates under the following conditions, we get rather surprising figures.

Bessemer plate.	Open-hearth plate.	Increase in the elastic ratio of Bessemer plate.	
Thickness $\frac{3}{8}$ in.	$1\frac{1}{2}$ ins.	Due to thickness	+ 9.00%
Phos. 0.07 to 0.10	0.05 to 0.07	Due to method of manufacture and higher phos.	− 4.10%
Fast speed	Slow speed	Due to pulling speed	+ 7.80%
Width, $1\frac{1}{2}$ ins.	$1\frac{1}{2}$ ins.	Due to width of test piece	+ 0.00%
Total increase			+ 20.90%

This difference of 20.9% in the elastic ratio of a 60 000-lb. steel equals a difference of 12 540 lbs. in the elastic limit of the material. These results are very instructive and will show the engineers who are asking for very high elastic limits that it is an easy matter to give them almost anything they want by using this "go-as-you-please" method of testing and by not checking the elastic limit as given by the drop of the beam, by using dividers on test piece, or any other method of check.

Taking another case of where high results are wanted on the plate $1\frac{1}{4}$ ins. thick:

Bessemer plate.	Open-hearth plate.	Increase or decrease in the elastic ratio of Bessemer plate.	
Thickness, $1\frac{1}{4}$ ins.	$\frac{3}{8}$ in.	Decrease due to thickness	−9.00
Phosphorus, 0.07 to 0.10	0.07 to 0.10	Increase due to method of manufacture.	3.52
Fast speed.	Slow speed.	Increase due to pulling speed	+7.80
Width, 40 ins.	1.50 ins.	Increase due to the width of test piece	+4.00
		Total increase	+6.32

Mr. Webster. This difference of 6.32% in the elastic ratio of a 60 000-lb. steel equals a difference of 3 792 lbs. in the elastic limit; that is, the 1¼-in. plate, even after the author's allowance of 9% in elastic ratio, gives about 4 000 lbs. higher elastic limit than the ⅜-in. plate. If the allowance of 9% on account of thickness is not made on the 1¼-in. plate, then there is 15.32% higher elastic ratio, or about 10 400 lbs. higher elastic limit than the ⅜-in. plate, which does not agree with the usual results in every-day work.

Last August the writer stated to the superintendent of the X Steel Works that the elastic limit of 38 000 lbs. called for in Mr. George H. Thomson's new specifications was too high for an ultimate strength of 58 000 to 65 000 lbs., with 26% stretch in 8 ins. He claimed that he could get it without any trouble. The writer offered to make a complete series of tests on the 200 000-lb. Olsen machine, at the Pottstown Iron Company's works, to decide if the high elastic limit was due to material or the method of testing. The offer was accepted, and a large number of tests were made of material manufactured by the X Steel Works. The results were as follows:

About 60 tests were made at Pottstown in the ordinary manner, taking the elastic limit by the drop of the beam, and checking the same by the use of dividers on the test piece. The machine has an electric automatic device for running out the poise, the weighing beam making and breaking the circuit. These results and those of X Steel Works on the same material were as follows:

Shape.	Ultimate strength. Pounds per square inch.		Elastic limit. Pounds per square inch.		Elastic ratio. Per cent.		Elongation in 8 ins. Per cent.		Reduction of area. Per cent.	
	X Works.	Webster.	X Works.	Webster.	X Works.	Webster.	X Works.	Webster.	X Works.	Webster.
Rounds.										
Bessemer	63 249	60 890	46 086	34 951	72.9	57.4	26.81	26.84	53.8	63.9
Open-hearth..	61 621	61 050	42 523	33 169	69.0	54.3	28.38	28.55	61.3	67.5
Angles.										
Bessemer	58 889	58 180	42 362	35 943	71.9	61.8	28.73	28.78	56.2	60.1
Open-hearth..	60 258	60 288	39 053	33 488	64.8	58.9	29.98	31.20	58.4	58.9

These results were a surprise to both experimenters, but the only difference to be found by correspondence in the methods of taking the elastic limits was that at the X Steel Works they had no automatic arrangement to operate the poise, and ran it out by hand. This brings in to a greater extent the personal equation of the operator than where the automatic arrangement is used, for he not only has to watch for the drop of the beam, but at same time must run out the poise.

Mr. Webster.

In order to compare the elastic limit as taken by the drop of the beam, under different conditions of pulling and poise speeds, and at the same time to check these results with the elastic limits taken by Mr. Olsen's autographic device, the following tests were made by Mr. E. A. Custer, of the Baldwin Locomotive Works, on an open-hearth round ¾-in. steel bar. The results tabulated are the averages of sets of three tests each :

	Pulling speed, 1 in. in 3 minutes. Speed of poise, 53 000 lbs. in 1 minute.*	Pulling speed, 1 in. in 3 minutes. Speed of poise, 19 840 lbs. in 1 minute.†	Pulling speed, 4 ins. in 1 minute. Speed of poise, 53 000 lbs. in 1 minute.†
Ultimate strength.....	57 340 lbs. per square inch.	56 300 lbs. per square inch.	58 870 lbs. per square inch.
Elastic limit :			
Autographic device..	35 990 lbs. per square inch.	36 250 lbs. per square inch.	35 890 lbs. per square inch.
Elastic ratio.....	62.8%.	64.4%.	60.9%.
Elastic limit :			
Drop of beam.....	37 300 lbs. per square inch.	37 720 lbs. per square inch.	40 530 lbs. per square inch.
Elastic ratio.....	65.1%.	67.0%.	68.8%.
Reduction of area.....	59.9%.	58.6%.	61.1%.

The greatest difference in the elastic limits as taken by the drop of the beam is 3 230 lbs. between first and third cases ; this is equal to a difference of 3.7% in the elastic ratio. The greatest difference in the elastic limits, as taken by the autographic device, is only 360 lbs. between the second and third cases, but the difference in the elastic ratio is 3.5%, owing to difference of 2 570 lbs. in ultimate strength due to difference in pulling speeds. The greatest difference in elastic limits, as taken by the autographic device, and those taken by the drop of the beam, is 4 640 lbs. in the third case ; this is equal to a difference of 7.9% in the elastic ratio.

As all of these tests were made on pieces cut from the same bar, the differences in results are due to the systems of testing used in each case; these differences would have been greater, no doubt, if there had been another set of tests made by running the poise out by hand.

The writer is also indebted to Mr. Custer for the diagram (Fig. 1) taken by the autographic device, on which he has noted the beam readings as taken by the drop of the beam. The beam readings are represented by ordinates and the elongation by abscissas. There is a well-defined break in the lines for speeds of 1 in. in 15 minutes, with very slight differences between readings by drop of beam and diagram. But in the case of a speed of 4 ins. per minute the line is very different and the bend much more gradual, with a difference in readings by drop

* Speed of poise greater than rate of applying weight.

† Speed of poise slower than rate of applying weight.

Mr. Webster. of beam and diagram of 3 730 lbs. These results were also sent to the superintendent of the X Steel Works, but he wanted further light on the cause of the discrepancy in them and sent six sets of six pieces, each of 2 x ⅞-in. bars, to different mills and manufacturers to be tested.

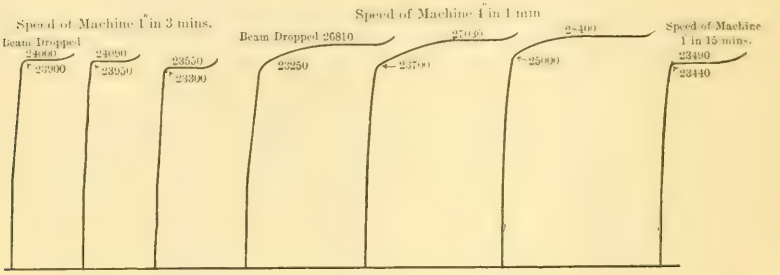

FIG. 1.

The pieces sent to one party were too short for their machine, and Messrs. Riehlé Brothers tested these. The average result of each set of six bars was as follows :

	Ultimate strength. Pounds per square inch.	Elastic limit. Pounds per square inch.	Elastic ratio.	Percentage of elongation in 8 ins.	Percentage of reduction of area in 8 ins.
X Steel Works	61 220	42 295	69.1	29.58	61.60
Webster	61 233	38 703	63.2	30.46	59.00
A	62 037	41 495	66.9	31.46	61.00
Baldwin	60 795	38 679	63.5	29.50	56.50
B	61 275	40 138	65.5	30.71	53.80
C	62 303	41 345	66.4	29.79	60.70
Riehlé Brothers	60 590	38 659 to 39 496	63.6 to 65.4	32.30	53.50

The greatest difference in the averages of the elastic limits of original observers is 3 716 lbs. between the first and fourth lines; this equals a difference of 5.6% in the elastic ratio. But the greatest difference in the elastic ratio is 5.9% between the first and second lines; this is due to the ultimate strength being higher in the second line than in the fourth, and giving a lower elastic ratio, although the elastic limit is slightly higher than in the fourth line.

The writer endeavored to get another set of these test pieces from the X Steel Works in order to have the elastic limit taken by the extension of the test pieces using the extensometer. They reported that they had none of the material left, but sent 10 pieces of ⅞-in. rounds from steel that had been thoroughly tested. Mr. Custer tested five of these pieces, and Messrs. Riehlé Brothers the other five. The results were as follows :

Mr. Webster

	X Steel Works. Average of 25 tests	Mr. Custer. Average of 5 tests.	Mr. Custer. Average of 5 tests.	Riehlé Brothers. Average of * 5 tests.	Riehlé Brothers.
Ultimate strength.					
Pounds per square inch.	60 123	60 036	.....	61 655	
Elastic limit.					
Pounds per square inch.	43 159	41 409	39 582	39 988	40 777
Elastic ratio, per cent....	71.8	69 0	65.9	64.8	66 1
Method.....	.....	Drop of beam.	Autographic device.	Average of 4 tests; extensometer and electric contact.	1 test by drop of beam.
Elongation in 8 ins.					
Per cent.	30.16	30.75	.....	28.93	
Reduction of area.					
Per cent.....	66.80	67.78			

* The figures for elastic limit in this column are for four tests only.

Tests of Mild Steel Plate Pieces, Measuring 2 x ¾ Ins.

Load per Square Inch.	10 027 Reading.	10 027 Stretch per 1 000 lbs.	10 028 Reading.	10 028 Stretch per 1 000 lbs.	10 030 Reading.	10 030 Stretch per 1 000 lbs.	10 065 Reading.	10 065 Stretch per 1 000 lbs.	10 066 Reading.	10 066 Stretch per 1 000 lbs.
25 000..	.0042	.000168	.0062	.000248	.0016	.....	.0084	.000336	.0038	.000152
26 000..	.0044	.0002	.0064	.0002	.0018	.0002	.0086	.0002	.0040	.0002
27 000..	.0047	.0003	.0068	.0004	.0020	.0002	.0088	.0002	.0042	.0002
28 000..	.0049	.0002	.0071	.0003	.0021	.0001	.0090	.0002	.0044	.0002
29 000..	.0050	.0001	.0073	.0002	.0022	.0001	.0092	.0002	.0046	.0002
30 000..	.0052	.0002	.0075	.0002	.0023	.0001	.0096	.0004	.0047	.0001
31 000..	.0056	.0004	.0079	.0004	.0025	.0002	.0098	.0002	.0049	.0002
32 000..	.0058	.0002	.0081	.0002	.0027	.0002	.0100	.0002	.0050	.0001
33 000..	.0060	.0002	.0084	.0003	.0029	.0002	.0101	.0001	.0052	.0002
34 000..	.0062	.0002	.0087	.0003	.0030	.0001	.0102	.0001	.0054	.0002
35 000..	.0064	.0002	.0090	.0003	.0031	.0001	.0103	.0001	.0057	.0003
36 000..	.0066	.0002	.0092	.0002	.0033	.0002	.0105	.0002	.0060	.0003
37 000..	.0068	.0002	.0095	.0003	.0037	.0004	.0108	.0003	.0062	.0002
38 000	.1838	.1770	.0098	.0003	.0039	.0002	.0170	.0062	.0064	.0002
39 000..	.2039	.0201	.0100	.0002	.0040	.0001	.0510	.0340	.0068	.0004
40 000..	.2148	.0109	.0426	.0326	.0041	.0001	.0740	.0230	.0088	.0020
41 000..	.2278	.0130	.1720	.1294	.0210	.0169	.2026	.1286	.0104	.0016
42 000..	.2490	.0212	.2055	.0335	.0780	.0570	.2180	.0254	.1950	.1846
43 000..	.2705	.0215	.2222	.0167	.0838	.0058	.2344	.0164	.2068	.0118
44 000..	.2790	.0235	.2416	.0194	.1087	.0249	.2542	.0198	.2202	.0134
45 000..	.2705	.....	.2606	.0190	.2235	.1148	.2788	.0246	.2390	.0188
46 000..	.2940	.....	.2820	.0214	.2410	.0175	.2948	.0160	.2552	.0162
47 000..	.....	.....	about .3080	.....	.2594	.0184	about .3200	.....	.2758	.0206
48 000..	.....	.....	.....	.....	.....	.....	.....	.....	.2972	.0214

	10 027	10 028	10 030	10 065	10 066
Elastic limit.....	38 000	40 000	41 000	38 000	40 000
Maximum load.....	57 460	60 840	62 960	60 490	62 290
Elongation. Per cent.....	33.1	31.0	33.0	32.3	32.5
Reduction in area Per cent.	52.1	54.6	48.85	53.33	56.24
Fracture.....	45° Silky. Cup.	Silky.	Silky. 45°.	Silky. Cup and 45°.	Silky. Cup and 45°.

Mr. Webster.

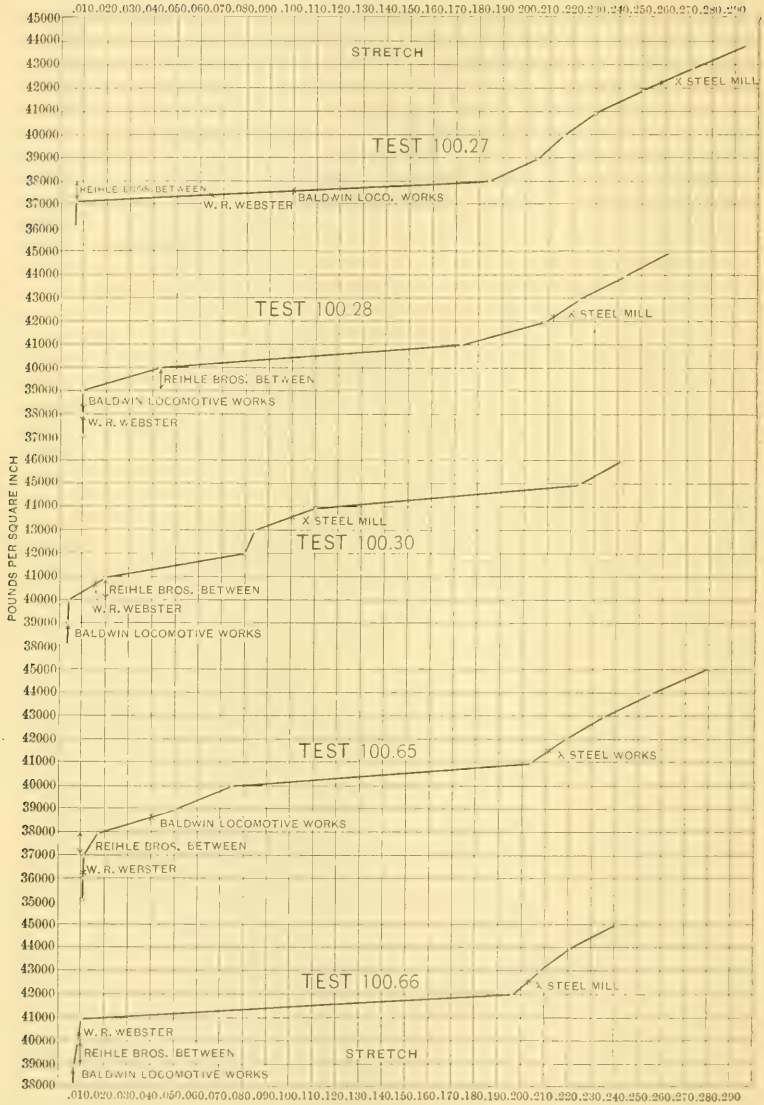

FIG. 2.

Mr. Webster.

After this Messrs. Riehlé Brothers made a complete set of tests on one of the original sets of 2 x ¾-in. test pieces, taking the extensions for each increase in load of 1 000 lbs. per square inch from 30 000 to 44 000 lbs. Their results are given in full, with diagrams of the extensions (Fig. 2). The writer is under obligations to Mr. Wille for a full analysis of the broken test pieces as well as for the diagrams (Fig. 2).

The tests summarized in the second table on page 375 were made with a Riehlé-Buzby extensometer, which was set at zero for a zero load. The readings represent actual extensions for each increase of 1 000 lbs. per square inch in the loading. The first load to about 24 000 lbs. per square inch was applied with a head-fall of 1 in. in 64 seconds. From that point to beyond the limit, at $\frac{1}{8}$ in. per minute, and then at 0.2 in. per minute, until the test piece showed a slight reduction at the breaking point. From that point to the break, a head-fall of 0.4 in. per minute was used. In a letter accompanying the above table, Messrs. Riehlé Brothers state:

"Please note that the elastic limits shown are for the first 1 000 lbs. per square inch above the limit. In the absence of any definite instructions on this point we simply took the first reading showing disproportionate stretch; hence all these quantities should be more or less minus. In the case of No. 10 027, the limit was probably about 37 200 lbs. per square inch, while in No. 10 028 it was probably 39 800 lbs. per square inch, as indicated by the amount of extension."

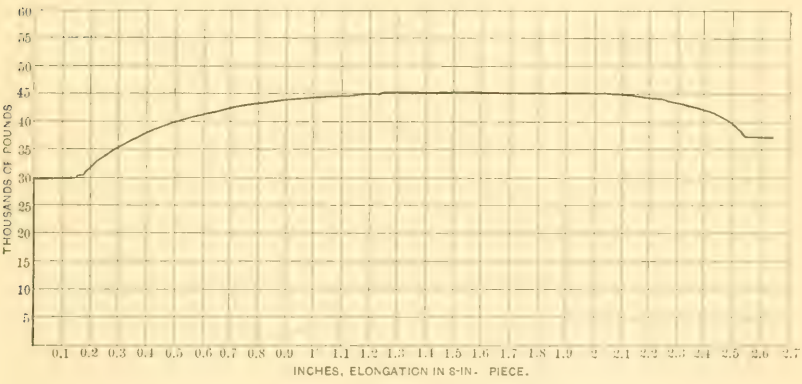

FIG. 3.

A sixth piece was tested autographically and the diagram (Fig. 3) is reproduced from the chart made by the machine, which has an automatically balanced beam. The vibration of this beam closes a circuit which operates a clutch propelling the poise. The elastic limit of this piece was 39 957 lbs. per square inch; the maximum load, 59 550 lbs. per square inch; the elongation in 8 ins., 32.1%; the reduction in area, 54.4%, and the fracture 45° and silky.

Mr. Webster. The following letter was sent to the writer by Mr. Wille at the same time the strain diagrams (Fig. 2) were transmitted:

"I send you herewith stress-strain curves plotted from the results of tests made by Riehlé Brothers on samples of steel furnished by the X Steel Mills. These tests show that immediately after the elastic limit is passed the piece yields rapidly and then recovers quickly after which each augmentation of stress results in an approximately proportional increment of strain until the maximum stress is reached. This rapid yielding, recovery and subsequent stretching gives a drop of the beam at two distinct points on the stress-strain curve. The first drop is sometimes scarcely perceptible, the second usually very decided. You will notice that the X Steel Mills almost invariably take their elastic limit after the specimen has recovered from its greatest increment of stretch. I have marked the point recorded as the elastic limit by the different observers by a cross.

"It will be noticed that with one exception the X Steel Mills have recorded their elastic limits when the pieces had stretched 0.2 in. From this it would appear that they waited until the beam settled well down on the second fall. An inspection of the curves shows that ordinarily no error of serious magnitude would be made if the elastic limit be taken when the specimen has elongated as much as 0.1 in., considering soft steels only, and it would not be very difficult for an observer to catch the stress upon the piece under this strain either by the simple fall of the beam or by checking up with a pair of dividers, as the United States Testing Board did in its original tests.

"I also attach the analyses of these samples. In all cases duplicate determinations were made and some of the elements were determined by entirely different methods. The sulphur was determined by evolution, and perhaps on account of the high percentage of copper present, the results may be low. The carbon was determined by color comparison being made against a Carnegie 0.217 carbon open-hearth steel."

Analyses of 2 x ⅜-In. Steel Bars.

	10 027.		10 028.		10 030.		10 065.		10 066.		10 072.	
			First determination.	Second determination.	First determination.	Second determination.	First determination.	Second determination.	First determination.	Second determination.	First determination.	Second, determination
Carbon	.19		.18	....	.18	....	.18	....	.20	....	.18	
Manganese	.44	.45	.43	.47	.50	.53	.50	.52	.52	.49	.45	.47
Phosphorus	.078	.078	.091	.088	.092	.088	.071	.070	.076	.077	.074	.074
Sulphur	.025	.027	.038	.041	.035	.036	.039	.040	.035	.037	.032	.034
Copper	.13	....	.097	....	.086	....	.131	....	.10	....	.12	
Silicon	.002	....	.005	....	.005	....	.003	....	.003	....	.003	

The author claims a decrease of 6% in the reduction of area and 3% in the elongation when the thickness of plate is increased from ½ in. to 1¼ ins.; this may agree with the results of the two mills he refers to, but others get different results. The writer has a table compiled from

several hundred tests of one of our largest mills, and it shows an increase Mr. Webster.
of 6% in the reduction of area and 1% in elongation in going from ½ in. thickness to 1¼ ins. This would indicate that the differences observed are not due to the thickness of the material, but they may be accounted for by different methods of rolling, and different finishing temperatures in rolling. Too much importance cannot be given to this important branch of the manufacture of structural steel.

During the past four years, the writer has made a very exhaustive series of tests in order to find out the relations between the "chemical constitution of steel and its physical properties," and in the course of the work soon found out that the true starting point of the investigation was the heat treatment of the steel. The following is from his papers giving results of this work :*

"In all rolling-mill work it is generally conceded that the temperature at which the material leaves the rolls is an important element, as affecting the ultimate strength and stretch of the finished product. This is a hard matter to control, and the difficulty is greatly increased with long, wide or extremely thin plates, all of which would naturally be finished a little colder, and would therefore give higher ultimate strengths, while the chances are that very thick plates will be finished too hot. On tonnage work it is not easy to hold material back in rolling; and the temperature in finishing is controlled in various ways at different mills, with more or less success. But the difficulty is not recognized at all by the engineers in their specifications, which ask for the same results in all widths.

"Most of the specifications for steel assume that the ultimate strength and the relation between it and the stretch of a given grade of steel will be the same under all conditions, whether it be rolled into shapes, universal plates, or wide sheared plates. The ultimate strength under these conditions is only allowed to have a variation of 8 000 lbs., and in some cases very much less. The manufacturers have themselves principally to blame for this state of affairs, since engineers are only asking for results corresponding to test reports shown them by the manufacturers as representing what they could do, which, however, usually are not average results. As the differences due to the method of rolling, as well as the section of the finished product, are recognized in specifications for iron, they should also be recognized in those for steel.

"The relief most needed to-day is the adoption of one uniform specification and standard-size test piece, the method of testing being provided, and limits left broad enough to cover the variations referred to above. Proper allowance should be made for both ultimate strength and stretch in extremes of thickness, width or length."

The other points brought out in this investigation are that reliable results cannot be had with narrow test pieces cut from thick plates, and that heavy reductions in rolling which are sufficient to bring out the "second heat," as the rollers termed it, injure the material, no matter what the final finishing temperature may be. More tests are needed on this subject and close attention must be paid to heating of the blooms, reductions in rolling and finishing temperature.

* See the *Transactions* of the American Institute of Mining Engineers, Vol. XXI, p. 766.

Mr. Webster. The writer considers that many of the so-called mysterious failures referred to in the paper may be accounted for by improper heat treatment of the material. The author claims that most of them are due to phosphorus, and in this, no doubt, is right, yet in some cases the chemical analysis shows the material to be all right. It is in these cases that we should look up the heat treatment of the material before falling back on the gases to account for the trouble.

The writer is more firmly convinced than ever that the true starting point in any investigation of this kind is the heat treatment of the material, and back of that, of course, thermo-chemistry. In this connection the remarks of Mr. H. M. Howe on the "Pyrometry and Heat-Treatment of Steel" will be of interest.*

Mr. Howe. Henry M. Howe, Esq.—The author's words: "There is good testimony to show that the product of the converter is an inferior metal, which gives way in a treacherous manner under shock," seem to the writer unsupported by the evidence quoted, and inconsistent with the extensive use of Bessemer steel in Europe for bridge material. The words suggest, perhaps unintentionally, that inferiority and treachery are both unavoidable and habitual, which is a grave mistake. The author objects even more to basic Bessemer steel, because after its phosphorus has been removed, it may take it up again from the slag when the recarburizing reaction occurs. It is possible that he overlooks the recent advances which have been made in basic Bessemer procedure, by which the recarburizing occurs when only very little slag is in contact with the metal. Under these conditions, it is stated on credible authority, practically no phosphorus is taken up by the steel. Particular reference is here made to the Darby method of recarburization. In this, the slag is poured off as fully as possible; the remaining slag is then thickened by adding lime to it, so that it becomes so stiff as to tend to dam itself back; the metal is then poured out from beneath the slag, and as it runs a stream of fine coke or charcoal is shot into it, to recarburize it. Under these conditions it is hard to suppose that much rephosphorization can occur.

Many people whose opinions deserve weight have a strong prejudice against Bessemer steel. On the other hand, many others have the highest opinion of it; and, what is far more important, it is used extensively for objects, such as bridges and boilers, for which treachery would certainly unfit it. This is more particularly true of continental Europe.

This state of things can best be explained by the obvious supposition that if, in making Bessemer steel, certain classes of pig iron, viz., those too rich in silicon, be used, and if certain objectionable methods of manufacture be followed, treachery may result; but if proper mate-

*See the Presidential address before the American Institute of Mining Engineers, February, 1894.

rials, methods of manufacture, and inspection are used, such treachery can be absolutely prevented. It seems that any other explanation is excluded by the facts before us. Were this the proper place, abundant evidence could be given in support of the apparent trustworthiness of Bessemer steel, even of basic Bessemer steel. Mention may be made to a few striking instances, taken from an important work* by Professor Tetmajer, who has lately and very thoroughly examined the trustworthiness of basic Bessemer steel, and whose conclusions tally ill with the picture which the author draws. Indeed, it is surprising that he should have spoken as he does in view of Professor Tetmajer's results. The latter says that the use of basic Bessemer steel for railroad bridges is officially permitted by the English, French, Italian, German and Swiss railroads; that in some German basic Bessemer works with an annual production of from 12 000 to 15 000 blows, often a whole year will pass without a single blow which is cold short from phosphorus; and that, of 27 044 basic Bessemer rails on the Swiss Northeastern Railroad, only two broke between 1885 and 1893. Of these, 5 045 had been in use for eight years, 7 934 for seven years, 6 291 for six, and 7 774 for five years. Mr. Howe.

In summing up, Professor Tetmajer says:

"By the usual deoxidizing and recarburizing methods one can make in the basic converter rail steel which, as regards uniformity of composition and the absolute quantity of the non-ferrous elements (*assesorische Beimengungen*), is fully equal to the product of the acid process. By the use of Darby's recarburizing process one can make a pure carbon steel of any desired hardness with a degree of certainty which hitherto has neither been wished nor reached in rail-making" (even by the acid open-hearth process).

The author's proposition to test steel castings chiefly by means of test bars rolled from test ingots is surprising. The important things about a steel casting are (1) its freedom from cavities; (2) its chemical composition; and (3) the physical condition of the metal in the casting itself. Rolled test pieces do little more than tell of the chemical composition. Cavities close to a great extent in rolling, and the physical condition of the rolled metal tells us very little indeed of that of the castings which happen to have been made from the same charge. The physical condition of a rolled test bar is influenced profoundly by its rolling and the accompanying heat treatment, influences to which the casting is not exposed at all.

Test coupons, cast on a casting, and heat treated with it, tell quite as well as rolled bars do about the chemical composition; they give direct and very valuable information as to the physical condition of the castings, as affected by its casting temperature and subsequent heat treatment, and, if judiciously placed, they may give information as to its freedom from cavities. As to this latter point, important in-

* "Über das Verhalten der Thomasstahlschienen im Betriebe." L. Tetmajer.

Mr. Howe. formation may often be had by ascertaining the density of the whole casting, either by its weight and dimensions, or, if it be small, by weighing it first in air, then in water; and also by examining the parts where the heads and runners are cut off. When castings are made in large numbers from a single pattern, the best possible information may often be obtained as to their value by testing to destruction whole castings chosen at random. This is done, for instance, in case of car-coupler knuckles.

The direction that castings of simple form be used without annealing is astonishing. What is its purpose? Are steel founders who are skillful and careful in annealing to be deprived of the advantage of their skill and care? Are users to be deprived of the advantages of annealing? That such a provision might be acceptable in special cases, where a material intermediate in merit between cast-iron and annealed steel castings would suffice, can be understood by the writer, but such cases are not the rule.

He does not agree with the author that it is absurd to limit the carbon content of steel; that Mr. Riley's conclusions are not in accord with his premises; or that the recommendation to use the terms "yield-point" and "elastic limit" in their strict sense is unwise. Does the author forget that "elastic limit" was used as a physical term long before it had any commercial use, and that its scientific use has continued? It cannot be seen how he can escape from the fact that the term "yield-point" is unmistakable, while "elastic limit," if used in the way he prefers, is certainly ambiguous.

His recommendation that the material used for bridges should be even weaker than now seems in the wrong direction. The sacrifice of strength to a degree of ductility far greater than the metal can ever be called on to display in normal use, and which therefore is useless except to resist barbarous maltreatment, seems unwise. The wiser course is to move in the direction of using stronger material, and, by greater care in its treatment, to render such extreme ductility superfluous.

Mr Hartshorne JOSEPH HARTSHORNE, Esq.—On account of the writer's former connection with the only company which has operated the basic Bessemer process in this country upon a commercial scale for a term of years, he feels in duty bound to defend it.

The author has quoted from Mr. A. E. Hunt a sweeping condemnation of Bessemer metal for structural purposes, and has fortified it by quotations from Messrs. J. W. Wailes and W. H. White. The writer is strongly inclined to agree with the opinion of these gentlemen in respect to the Bessemer process, as usually carried out in this country and in England. It would, he is sure, meet with a vigorous denial from such manufacturers as the John Cockerill Company. Even were this opinion a universal truth, as applied to the acid Bessemer, it would not be fair to transfer it unquestioned to the basic Bessemer process, which should be considered solely on its own merits.

Mr Hartshorne

The author calmly annihilates the basic process in the following words: "The objections to Bessemer steel are many times emphasized in the product of the basic converter, for at the end of the operation there is often a very considerable percentage of phosphorus that passes back from slag to metal, and which is not always uniformly distributed. This fact utterly condemns it for the best of work." He then gives the reasons why this rephosphorization occurs in the basic Bessemer and not in the basic open-hearth process.

It is with this *ex cathedra* edict of condemnation that issue must be taken. When the basic Bessemer process is improperly and carelessly carried out there is always danger of rephosphorization. In the early days at Pottstown they suffered from it in common with most beginners, but the same is true of the basic open-hearth process.

The writer asserts positively, from personal knowledge and experience, that when the proper conditions are observed there is no more danger of rephosphorization in the basic Bessemer than in the basic open-hearth process. On the other hand the basic process produces metal which is better in many ways than that usually made in the acid converter. It is freer from sulphur and phosphorus in the average, and can be made freer from these elements than that which is made from the best selected acid stock. The soft steels can be made lower in carbon and lower in manganese than any acid Bessemer steel he ever heard of. It is more solid and freer from blow-holes in the ingot than acid Bessemer steel. Actual observations confirm this statement, which would be expected from the fact that properly made and cast basic Bessemer steel does not require to be capped in the molds, no matter how soft it is. It is less likely to be red-short from oxides or oxygen, or whatever it is that is corrected by manganese, and requires less manganese to be added to make it fit for use. One heat which had less than 0.10% of manganese in the finished material and was cast in 12-in. molds, was not capped at all and rolled perfectly into wire billets. That these assertions are true as to the characteristics of basic Bessemer as compared with acid Bessemer soft steel can be affirmed from an experience of 6 years with the former process and 10 years with the latter, together with much study of both processes in Europe.

Since the basic Bessemer process has reached its greatest state of development in Germany and Austria, it is natural that there also has this question of quality been most closely studied and reported upon. One of the most complete and convincing investigations on this subject is that by Professor L. Tetmajer, Director of the Testing Laboratory of the Polytechnical School of Zurich,* entitled, "A Contribution to the Soft Steel Question." Professor Tetmajer was formerly not a believer in the use of soft steel, and especially of basic Bessemer steel, for bridge-building. He saw reason to change this belief, and formulated his conversion as follows:

* See *Stahl und Eisen*, 1892, p. 558.

Mr Hartshorne "Recent investigations have shown that the much-feared unreliability, which is often caused by wrong treatment of the material in the work shop, is by no means an attribute of basic Bessemer steel alone, but occurs just as often in open-hearth steel; also that, owing to the progress made in the management and control of the basic Bessemer process, the certainty with which structural steel of any desired chemical and physical quality can be made, and the established fact that many failures are due to causes lying outside of the process proper, we are no longer justified in making a distinction between open-hearth and basic Bessemer steel for structural purposes. * * * Basic Bessemer steel can be made in the soft grades necessary for structural and bridge work with a certainty and regularity, as regards chemical composition and mechanical properties, in no way inferior to that of the open-hearth process."

This opinion is based on the following investigations:

A. Tests made on 100 heats, 700 tonnes, produced by the Prager Eisenindustrie Gesellschaft, at Kladno, for a bridge at Melnik. Phosphorus was below 0.05% in all of this.

B. Chemical analyses of 48 consecutive heats made at Kladno before the Austrian Committee on Ingot Metal. Phosphorus between 0.021 and 0.032 per cent.

C. Inspection of material from the Rothe Erde Works, near Aix-la-Chapelle, for a bridge for the Wriezen-Jaedecker Railroad, 1891. Eighty-three heats, 800 tonnes of material. Phosphorus between 0.03 and 0.08%, 249 tension tests and numerous other ones were made. No tests that did not come within the specifications. No rejections from any cause.

D. Experiments made by the management of the Royal Railways of Bromberg, at the Rothe Erde Works. One thousand seven hundred pieces, representing several thousand tonnes, were examined. Sixty-one heats showed phosphorus between 0.023 and 0.093 per cent. All of the bending and breaking tests were faultless.

E. An examination of one year's product of beams for railroad cars at the Salgo-Tarjan Works, covering 100 heats, with 247 tension tests and the usual bending tests. Out of these heats only two exceeded 4.5 tonnes per square centimeter (63 990 lbs. per square inch).

F. Results of the tests made to date on the material for the bridge over the Vistula at Fordon. Three hundred heats from Rothe Erde Works tested with no rejections. Ultimate strength between 3.9 and 4.5 tonnes per square centimeter (55 458 and 63 990 lbs. per square inch); elongation, from 20 to 32%; phosphorus, below 0.10 per cent. All bending tests flawless.

G. Inspection of material for bridges for the St. Gothard Railroad, the steel coming from De Wendel's works at Hyange. There were 1 571.4 tonnes of structural material, and 61.6 tonnes of rivet material made from 374 heats. No rejections.

Professor Tetmajer also comes to the following conclusions: It is

more difficult to get good steel from the basic Bessemer process; the variations between the chemical composition of ingots generally fall within the allowable limits of error in analysis; the last ingot may have too much manganese if the ferro-manganese added remains unmelted; there is no difference in the position of the blow holes in the basic Bessemer and open-hearth metal, provided the chemical composition, the deoxidizers added and the casting temperatures be the same in both instances. He says finally: "The opinion that open-hearth metal is more solid than basic Bessemer metal is erroneous, and is flatly contradicted by our numerous tests on boiler plates from various open-hearth works." Mr Hartshorne

Professor Tetmajer has also published a paper* on "Basic Bessemer Metal as Rivet Material." These rivets were for bridges of the St. Gothard Railroad, and of the Swiss Northeastern Railroad. They were rolled, made and stored by heats, so that full control was possible. Tests ingots were taken during the casting of the third or fourth ingot, from which a tension test and chemical analysis were made. The latter were checked at Zurich, at first on every heat, later on every two heats. The following tests were made on two rods taken from different ingots of each heat, namely, a tension test, a cold bending test in the condition as delivered, a similar test after quenching, a similar test after being nicked, a hot bending test, and two upsetting tests. All of the heats were below 0.09% in phosphorus, 47 below 0.07%, and 36 below 0.06 per cent. All of them were below 4.2 tonnes per square centimeter (59 724 lbs. per square inch), and 36 below 3.9 tonnes per square centimeter (55 458 lbs. per square inch); all of them were above 26% in elongation and 24 were above 30 per cent. As a result of his investigations Professor Tetmajer comes to the conclusion that the basic Bessemer process can be carried out with sufficiently complete regularity and certainty, when properly conducted and superintended.

A very complete investigation of basic Bessemer metal was made in connection with the bridge over the Vistula at Fordon, which was reported upon by George C. Mehrtens, Government Railroad Director at Bromberg.† This investigation is especially interesting as it also included open-hearth metal for the same bridge. Seven hundred heats of basic Bessemer metal were tested, and 508 heats of open-hearth metal. None of the Bessemer heats were rejected, while 16 of the open-hearth heats could be not accepted. The system of testing was most exhaustive.

Samples of finished material were taken from three different ingots of each heat, and the following test made from each of them: a drawing-out test, a cold bending test, a bending test after quenching, a

* See *Stahl und Eisen*, 1893, p. 625.

† See *Stahl und Eisen*, 1892, p. 593, and 1893, p. 275.

Mr Hartshorne flattening and bending test, and a tension test. There were, therefore, as a general rule, 15 different tests made on each heat. Photographs of these tests have been reproduced in Mr. Mehrtens' paper before the International Engineering Congress in Chicago.*

Besides the three ordinary tension tests, two extra ones were taken from different ingots on every tenth heat. Carbon, phosphorus and manganese were determined in each heat, and silicon and sulphur in every tenth heat. Besides the above-mentioned tests, there were others made, as shown in the photographs referred to. These were bending, hot and cold drifting, and drop tests.

All of the 700 basic Bessemer heats were below 0.10% in phosphorus, 633 were below 0.08%, and 303 were below 0.06 per cent. All of them were below 43.8 tonnes per square centimeter (62 284 lbs. per square inch), in ultimate strength, 636 were below 43.0 tonnes per square centimeter (61 146 lbs. per square inch), and 550 were below 42.0 tonnes per square centimeter (59 724 lbs. per square inch). All of them were above 21% elongation, all but one above 23%, 682 were above 25%, 316 were above 28 per cent. All but one of the 508 open-hearth heats were below 0.08% in phosphorus, and 489 were below 0.06 per cent. All but two of them were below 45.0 tonnes per square centimeter (63 990 lbs. per square inch); 408 were below 43 tonnes (61 146 lbs.), and 187 were below 42 tonnes (59 724 lbs.). All but one heat were above 20% elongation, 471 heats were above 23%, and 262 were above 28 per cent.

Very complete and interesting tables of the results of the tests and analyses accompany this paper, which go into the subject in great detail. Mr. Mehrtens concludes as follows: "Whoever sufficiently studies the above plates and tables will reach the conclusion that no longer can any objection exist to the use of a good soft steel, and that basic Bessemer (Thomas) metal has become the equal of open-hearth metal."

Coming to the writer's own experience, he can say that it has led to the same conclusions as those enunciated by Mr. Mehrtens and Prof. Tetmajer. Unfortunately the records of the steel works of the Pottstown Iron Company are not now accessible, and he cannot, therefore, produce as much corroborative evidence as he otherwise would be able to, and will have to depend somewhat on his memory.

During the early days of the work at Pottstown, there was undoubtedly trouble from rephosphorization, and a good deal of time and labor was spent investigating its causes. It was due, in a large measure, to a thin slag, whether the latter was owing to too high a temperature, or to a low melting point caused by too low a basicity. Acting on this information, and taking other precautions, it was possible to prevent rephosphorization to any appreciable extent. The presence of enough lime was first insured to make the slag sufficiently

* See the *Transactions* of the American Society of Civil Engineers, Vol. XXX, p. 204.

basic under all conditions, and the temperature of the blow was regulated so as to keep the slag below the danger point. It was sufficient, for prevention of rephosphorization, to chill off the slag. During the last three years of work at this plant no direct evidence of rephosphorization was found, either in the vessel or in the ladle. During the last 18 months 80.52% of the product was below 0.06% of phosphorus, 17.63% was between 0.06 and 0.10, and 1.85% was above 0.10. It must be remembered that some of the product was of such a character that 0.12% phosphorus was not objectionable, and that it is cheaper to stop the after-blow as soon as possible. For the last six months there was 86.68% of the product below 0.06%, 12.44% between 0.06 and 0.10%, and 0.88% above 10% of phosphorus. About one-half of the product was 0.04% or less. There was no difficulty in getting below 0.03% in phosphorus, when it was necessary to do so. Mr Hartshorne

Many analyses were made to test the regularity of the steel in the different ingots of a heat. One series of such analyses is given as typical of them all; it may seem to show slight rephosphorization.

TABLE No. 1.

Blow No.	Ingot No.	C.	P.	Mn.
6997	1	0.09	0.040	0.630
	2	0.10	0.030	0.740
	3	0.11	0.040	0.650
	4	0.09	0.035	0.650
6998	1	0.08	0.035	0.325
	2	0.08	0.030	0.320
	3	0.08	0.030	0.325
	4	0.08	0.040	0.300
6999	1	0.08	0.045	0.415
	2	0.08	0.035	0.425
	3	0.08	0.050	0.405
	4	0.08	0.035	0.415
7000	1	0.10	0.035	0.425
	2	0.10	0.050	0.390
	3	0.11	0.055	0.455
	4	0.10	0.055	0.445

It will be noticed that the first ingot of the last two heats is lower than the others. This may indicate rephosphorization, but probably indicates segregation. If the former were the case, it should increase in the later ingots, as this trouble is cumulative. This, however, has not happened.

An example is also given of a number of more complete investigations which were made as to the regularity of the steel. The ingots were 16½ x 20½ x 78 ins., and were rolled into slabs 19½ x 2½ ins. in section. Samples for analysis were taken every 4 ft., beginning 2 ft. from the top end.

Mr Hartshorne

TABLE No. 2.

Ingot No.	Sample No.	C.	S.	P.	Mn.
First ingot cast	1	0.06	0.030	0.020	0.205
	2	0.06	.....	0.020	0.205
	3	0.06	.....	0.020	0.210
	4	0.07	.....	0.020	0.215
	5	0 06	.....	0.020	0.220
	6	0.06	.....	0.030	0.220
	7	0.07	.....	0 030	0.230
	8	0 06	.....	0.020	0.195
Second ingot cast	9	0.06	0.030	0.025	0.205
	10	0.05	.....	0 025	0.210
	11	0.05	.....	0.025	0.210
	12	0.07	.....	0.025	0 210
	13	0.05	.....	0.030	0.220
	14	0 05	.....	0.020	0.225
	15	0.07	.....	0.030	0.210
	16	0.07	.....	0.020	0.210
Third ingot cast	17	0.06	0.029	0.025	0.205
	18	0.07	.....	0 025	0.210
	19	0.06	.....	0.020	0 205
	20	0.07	.....	0.025	0.200
	21	0.07	.....	0.020	0.210
	22	0.07	.....	0.020	0.205
	23	0.07	.....	0.025	0.210
	24	0.07	.....	0.020	0.220
Fourth ingot cast	25	0.07	0.033	0.025	0.190
	26	0.07	.....	0 025	0.175
	27	0.06	.....	0.025	0.175
	28	0.07	.....	0.025	0.215
	29	0.07	.....	0.020	0.190
	30	0.06	.....	0.025	0.195
	31	0.07	.....	0.025	0.180
	32	0.07	.....	0.025	0.200

Many such series of analyses as those given in these two tables were made, all of which showed about the same results, and none furnished any more evidence of rephosphorization. The physical qualities of the steel, when properly handled at the casting pit and in the rolling mills, followed very closely the chemical composition. Mr. William R. Webster has shown this very completely in his papers* before the American Institute of Mining Engineers and the British Iron and Steel Institute. The tables of tension tests there given show the physical quality of the steel most completely. It is not worth while to repeat any of them here. They show the same general result as those quoted from the German sources. The above data will show most conclusively that basic Bessemer steel, when properly made, with due care and knowledge, is fully equal to open-hearth steel of like chemical composition, when made with like skill and carefulness.

For the purpose of eliminating the danger of segregation, the objectionable elements, especially sulphur and phosphorus, should be made so low that, should the entire amount be concentrated in half of

* See the *Transactions* of the American Institute of Mining Engineers, Vol. XXI, p. 766, and Vol. XXIII, p. 113; also the *Journal* of the Iron and Steel Institute, 1894, Vol. I, p. 328.

the ingot, the steel would still be within the limits. This is the only method of preventing the bad results of segregation which present knowledge reveals. The author has stated very clearly the effect of the various elements in steel, and the writer's experience agrees with his in general. On one or two points, however, it differs. Sulphur appears to increase slightly the tensile strength of plates, while, as the paper states, it does not seem to effect the elastic limit, elongation or reduction. Mr. Webster's investigations show quite clearly that manganese does increase the tensile strength of soft steels, but that its influence per unit is lessened as its content increases. Mr Hartshorne

In the experience at Pottstown, it was found that phosphorus did effect the elongation, as well as the tensile strength, of test pieces cut from plates. When ¼-in. round rods are tested, it often seems not to have any appreciable influence, even when present in amounts too high to be permissible in structural steel.

The writer agrees with the paper thoroughly in thinking it better practice to cast large ingots and then bloom them to slabs before rolling into plates, but his reasons for thinking so are purely what might be called matters of economy and convenience. The experience of the American plate mills has certainly shown that just as good plates can be rolled direct from an ingot as those which are rolled from a bloom. The decision between these two methods of procedure will be decided in most cases by the answer to the question as to what costs most in the end. Experience has led him to believe that, after enough work has been done on an ingot to close up the blow holes and to bring the grains in close relation to each other, further work has no effect as such. It is only necessary that this work should be done at a temperature below Chernoff's point *b*, that is, the point below which steel does not change its structure. Any work which is done beyond that strictly necessary for consolidation has its effect solely as it determines the temperature at which the metal operated upon leaves the rolls or hammer. In this belief he has only followed the path pointed out by Mr. James Riley, as cited in the paper. Mr. Riley was and is right in the position he then took. He is certainly strongly supported by the investigations of Messrs. Sauveur, Webster and others.

It is not yet settled that segregation is greater in large than in small ingots, and there is some evidence that the reverse may be the case. As the author suggests, it is an easy matter to cut the part most effected by segregation into scrap. If this is too heroic an operation, it can at least be used for an inferior finished product. The author has incidentally remarked that the difference in cost in favor of the basic hearth disappears when steel with over 0.08% phosphorus is being made. This is too sweeping an assertion, as it is largely a question of locality, depending for its answer on the cost of pig and scrap. In one instance there was at least a dollar a ton in favor of the basic hearth for the cheapest grades of steel.

Mr. Greiner. J. E. GREINER, M. Am. Soc. C. E.—Specifications for structural steel, no matter how carefully or by whom drawn, will have certain features more or less subject to criticism. As to the method of manufacture, there can be no question, since open-hearth steel, whether it be basic or acid, is the only material which any engineer is justified in using in structures subject to vibrations or shocks.

There is still a lurking skepticism as to the superior quality of the basic open-hearth metal, owing to an inferior grade of stock which is used, but the writer has not as yet been able to offer any objections to any soft basic steel which has been made during the past two years for various structures built on the lines of the road with which he is connected, although this material is subject to severe punching and drifting tests in addition to the ordinary specification requirements. He has, however, met with a case of acid open-hearth steel having an ultimate strength slightly above the upper limit of soft steel requirements, which when rolled into a channel and built up into a post under the same conditions as wrought iron, showed a crack through one flange across the web to the root of the other flange. It is certain that this crack was not in the material before it left the shop, and the channel must have cracked either during the unloading at the bridge site or during transportation. This is the only case, however, of failure of open-hearth steel which has ever come to the writer's notice, and the cause of this failure could not be traced, although careful tests and chemical analyses were made of the channel adjacent to the fracture and of different parts throughout its length.

Manufacturers who make acid steel exclusively naturally believe that the product of the acid furnace is superior to that of the basic, no matter whether a soft or medium steel is required ; but it has been found extremely difficult to obtain an acid steel which will always meet the specification requirements of soft steel, the tendency being to run over 60 000 lbs. in ultimate strength, and when any question is raised about the acceptance or rejection of material which is too high, the manufacturer will invariably argue that the acid steel, even when it goes far above specification requirements, would be better than a basic steel owing to the greater certainty of uniformity in the material itself. Should this same manufacturer roll his shapes from basic billets and the tests fall below specification requirements, he will argue that it is the best material to use, because it is much softer and can be manipulated in the shop without any danger of injury, and would be better able to stand the wear and tear of heavy traffic when placed in a bridge.

So far as a chemical analysis is concerned, it is the writer's practice to limit the phosphorus to 0.08% for acid and to 0.05% for basic metal, and to make a sufficient number of punching, drifting, bending and quenching tests to be reasonably certain that there is no

excess of injurious elements, and satisfy himself that the material is perfectly safe for all structural purposes. Mr Greiner.

It is extremely unfortunate that there is no good way of applying satisfactory shock tests, as strains due to shock are what engineers fear more than anything else. It is rather peculiar that when bars which have stood 25 to 30 years in a bridge break on account of excessive loading, they break suddenly and without warning, and show neither a reduction of area or elongation, and generally have a granular or crystalline fracture. If a suitable impact machine were designed to thoroughly test metal for shocks, punching, drifting, bending and quenching, the writer would give much more consideration to such tests than to the ordinary elastic limit, ultimate strength and reduction of elongation of test pieces regularly made for purposes of record. When the usual excellent qualities of soft steel are recognized, this grade of material will be worked in the shops just as wrought iron is worked, and at the same time safe working stresses will be increased from 10 to 15 per cent. When medium steel is used, it is generally rolled into eye-bars, which, after being annealed, practically converts the material into a soft grade of steel, and while, therefore, some specifications require soft steel in all shapes and plates and medium steel for eye-bars, the bridge will practically contain nothing but soft steel. When it is desired to use high working stresses so as to cut down the dead weight in long spans, a medium grade of steel having all sheared edges planed off, and all holes drilled, is the best practice.

The author of the paper must not think that engineers are ignorant of the tricks practiced by the manufacturers, and if inspectors allow the manufacturers to select the most favorable parts of their plates or shapes for testing purposes, it is done with open eyes, although it would be an easy matter to so frame the specifications as to make the selection of test pieces rest entirely with the inspector, who could then select a plate or shape rolled the full length, out of any lot of material, and have it cut up into test pieces under his own supervision. This, however, is a degree of refinement not usually practiced unless the employees of certain manufactories have demonstrated by their tricky practices that it is absolutely necessary to take such extraordinary precaution.

Concerning the author's specifications, little need be said except perhaps that there are too many shades of differences in the physical requirements. When soft bridge steel is specified, it should be sufficient to give an upper and a lower limit varying by 8 000 lbs., and all material can be made to come within these limits without any difficulty. The writer, however, would place the lower limit at 52 000 lbs., and the upper at 60 000 lbs., instead of 47 000 lbs. and 58 000 lbs., as given by the author of the paper, and for medium steel he would place the limits between 60 000 and 68 000 lbs., instead of between 53 000

Mr. Greiner. and 64 000 lbs. The author's hard steel is practically what is usually considered a medium bridge steel, and the writer can see no good reason for changing the name.

Mr. Goldmark. HENRY GOLDMARK, M. Am. Soc. C. E.—It is satisfactory to learn that, even from the standpoint of a metallurgist, the specifications now in use are not unduly burdensome. For practical reasons it is desir-

TESTS OF DIFFERENT INGOTS OF THE SAME HEAT.—ACID OPEN-HEARTH STEEL.

Heat Number.	Ingot.	C.	Elastic limit. Pounds per square inch.	Ultimate strength. Pounds per square inch.	Elongation. Percentage in 8 ins.	Reduction of area. Per cent.
4 525	1	0.25	56 660	78 700	25.0	53.3
	1	.....	54 270	78 500	25.0	55.3
	2	0.22	51 070	74 070	25.0	58.2
	2	.....	51 560	74 700	25.7	55.5
	3	0.21	53 490	76 070	25.5	58.6
	3	.....	52 570	74 770	26.0	59.0
	4	0.22	47 320	72 180	25.5	55.5
	4	.....	46 500	72 150	27.2	58.6
	5	0.21	46 370	73 530	24.0	52.7
	5	.....	46 130	73 750	27.0	58.8
	6	0.21	47 420	72 130	27.0	55.5
	6	.....	47 960	70 360	26.5	56.5
4 532	1	.....	54 000	85 780	21.3	44.8
	1	.....	53 070	86 300	23.2	44.8
	2	.....	53 930	83 760	24.6	56.4
	2	.....	54 720	83 420	24.0	54.7
4 533	1	0.35	51 390	81 340	23.5	48.7
	1	.....	51 470	81 300	23.7	46.0
	2	0.34	49 270	80 800	25.0	54.1
	2	.....	49 630	81 360	25.7	54.9
	3	0.35	51 380	84 240	24.7	52.4
	3	.....	51 970	83 200	24.0	52.3
	4	0.37	48 820	83 660	23.0	44 5
	4	.....	50 780	84 420	22.5	41.4
	5	0.35	51 930	83 760	23.5	45.0
	5	.....	50 700	84 200	22.3	49.5
	6	0.35	54 210	83 760	22.7	43.6
	6	.....	55 270	84 640	22.8	46.9
	7	.....	49 500	81 240	22.7	48.6
	7	.....	51 110	82 080	24.9	50.0
	8	.....	50 200	81 760	24.8	48.3
	8	.....	51 190	82 480	23.3	48.3
	9	.....	49 130	82 560	22.7	46.2
	9	.....	50 960	82 460	22.3	44.7
	10	0.34	52 530	82 980	23.0	45.3
	10	.....	53 525	84 100	22.5	44.9
*	10	.....	49 690	80 170	22.0	51.2
4 536	1	0.22	54 860	78 170	25.1	56.0
	1	.....	55 670	78 810	24.6	57.6
	2	0.23	50 750	76 730	25.2	54.1
	2	.....	50 870	76 860	23.9	54.0
	3	0.25	54 100	76 220	26.2	53.4
	3	.....	49 700	77 230	25.0	54.0
	4	0.21	48 450	77 280	24.2	56.7
	4	.....	48 780	78 090	25.7	57.3
	5	0.22	47 740	74 180	27.0	54.5
	5	.....	47 520	74 490	26.2	54.6
	6	.....	50 600	78 820	23.9	49.4
	6	.....	51 650	79 050	25.0	46.3
	7	0.22	50 570	75 740	25.3	52.7
	7	0.23	51 310	76 300	25.0	50.1
*	7	.....	47 530	72 420	21.6	56.6

* Annealed.

able that the methods employed in testing shall be simple and uniform, as the refined appliances of the laboratory are clearly out of place in the every-day routine of the commercial testing room. Mr. Goldmark.

Besides this, complicated and unusual specifications involve considerable extra expense, so that it is to the interest of the consumer to do away with them as much as is possible, without impairing the quality of the material. For these reasons it is very important to know how closely ordinary methods enable a judgment to be made of the material to be used. Extended chemical and physical investigations on the different grades of steel are greatly needed in this field, and would amply repay the time and money expended on them.

In the meantime something may be done by engineers in charge of these testing laboratories to supplement their ordinary work by such additional tests as can be easily made from material at hand. As all testing must necessarily be done by sample, any information as to the degree of uniformity that prevails in the metal is of value. In the case of steel, the "blow" or "heat" is the natural unit, and it is, further, usual to confine the test to a single ingot. The tests given on the opposite page were made to determine the amount of variation likely to prevail in different ingots of the same cast, and are considered of sufficient value to be put on record. The results are quite satisfactory and indicate that the variation of 8 000 lbs. in the ultimate strength usually allowed is fair to the maker, while not excessive from the engineer's standpoint. The test pieces were ¾-in. rounds made from 20-in. square ingots, and were not machined. The duplicate tests of each ingot are from the same rod.

HENRY B. SEAMAN, M. Am. Soc. C. E.—The paper presents an accumulation of data which is particularly valuable as corroborating conclusions already reached. For instance, the data as to speed of testing shows that below the author's proposed minimum the speed of testing has little effect upon the practical result. His proposition to regulate the time of testing by the speed of screws, however, is not practicable, because it does not regulate the rate of increase of the applied strain per square inch The screw speed, when applied to a specimen 6 or 8 ins. between shoulders, would produce a far greater strain than if applied to a specimen without shoulders and with the jaws of the testing machine 12 to 14 ins. apart, and finally, when applied to full-size bars, varying from 4 to 40 ft. in length, it is entirely impracticable. The true criterion is pounds per square inch per minute, and from this the inspector must deduce the speed of his machine, either by calculation or by direct readings of applied strain. Even the minimum speed proposed by the author is too rapid to give any reliable intermediate data on short specimens, and will serve to raise all results except stretch. The proposition of Mr. Lewis to abandon intermediate data, is perhaps prompted by this thought. Mr. Seaman.

Mr. Seaman. Some years ago, when the question first arose as to whether engineers should specify the chemical composition of steel, the inclination was to leave this to the contractor. In order to thoroughly test the finished product, the uniformity as well as the strength and ductility of the entire product must be demonstrated. The disclosures made by the author in regard to the practice of hoodwinking inspectors, is, at least, startling. He repeatedly states "this is not dishonest." What, then, shall be the standard of integrity ?

If steel is so variable in each piece as the author indicates, how can the uniformity of the entire pile be judged ? He writes:

"If every plate is to be tested, then a coupon is left upon each corner, and a contiguous strip is privately" (*i. e.* secretly) "tested by the maker. After finding which corner gives the best results, the other coupons are cut off and the plate submitted to the inspector. This is not dishonest, for any one corner represents the plate just as much as any other corner, and it would manifestly be unfair to designate from which corner the test is to be taken."

And yet this is just what the manufacturer does by this practice. He "designates from which corner the test is to be taken." It is the engineer's duty, not only to design the structure, but to see that it is built as designed, and that no single member is deficient in strength. To accomplish this, it is necessary, either to test every piece, or to be otherwise assured by its uniformity, that the testing which is done exposes the worst material used. How is this possible, with the practice outlined by the author ? Such practice cannot be too severely censured. The yield point is higher than the elastic limit, and will more readily fill the specifications. The limit of elasticity is that point of strain beyond which the material will not recover its former state upon the removal of the applied load. An inspector of one large trunk line still continues to test this point by the removal of the load when the prescribed limit is reached, and the writer considered this practice correct. As a matter of fact the elastic limit is now rarely found in testing, but the yield-point instead as indicated by the drop of the beam.

In reading the author's suggestion as to a sliding scale for the required ultimate strength of various specimens, the writer has wondered whether the author anticipated a corresponding sliding scale of allowable strains in engineers' offices. He seemed to forget that material is rolled to fulfill the requirements of the structure already designed, and that the structure is not designed to use up the various grades of marketable material.

Mr. Deans. JOHN STERLING DEANS, M. Am. Soc. C. E. - The Society has rarely before it for discussion more important subjects than those of uniform methods of testing and standard specifications for structural material. Both the engineer and the manufacturer are equally concerned, and this is evidenced by the unusual interest taken in the report and paper just presented. It is seldom a paper covers the ground so satisfactorily

as this ; it presents facts well known to the manufacturer and to those engineers who have had special advantages enabling them to gather this particular information and experience: but to the majority it will be the first time that the reasonableness of the appeal of the manufacturer, that a "uniform specification" and a "possible specification" be decided upon and adhered to, has been presented to them in a full, concise and convincing manner. To those engineers who have been content with tests of the finished material, not caring to be informed as to the mode of manufacture, the facts brought out will have peculiar force. These engineers will certainly hesitate to use a product which lacks uniformity and reliability, even though individual specimens may fulfill their specifications. As has been said by a well-known authority, in speaking of steel, "the unexplained failures can invariably be traced to the Bessemer product." Open-hearth steel has proved its superiority as a reliable metal of uniform quality in so many instances, that its claims upon the confidence of the engineer will at this day hardly be disputed. It is certainly a more expensive metal, and the engineers should protect those steel-makers and manufacturers who propose to give them the best product, against the cheaper and inferior material; or, if they decide, for special reasons, to accept the inferior metal, they should see to it that they receive the benefit of the reduced cost. Several construction companies have long felt this handicap, and have been waiting for engineers to appreciate the difference in the reliability of the two products, and also the difference in their cost and value. Mr. Deans.

Referring to the question of specifying the chemical composition, it hardly seems necessary or proper to limit a steel-maker to any special percentage of the various elements, except in the case of those elements which, being present, would cause injury, and at the same time could not be determined by the physical test if present to an injurious extent.

In the case of phosphorus, this element may be present to an injurious extent, and the fact will not be shown by the most rigid ordinary physical specification. It would therefore seem most reasonable to limit the quantity of this element to a point below which it will have no deleterious effect on the metal, either during its manipulation in the mill or shop, or in actual use in the completed structure. This requirement is necessary to protect the engineer in his design, and it does not place upon the manufacturer of any section an unnecessary restriction. In no other way than by a combination of the physical requirements with this chemical test has the manufacturer been able to guarantee the product of his furnace as a metal of unquestioned reliability.

For the above reasons it seems not only unnecessary to give a more complete chemical specification, but, in addition, such complete speci-

Mr. Deans. fication would result in harm in tying the hands of the producer to just this extra extent, give an unjust advantage to particular plants, and increase unnecessarily the cost to all without any corresponding advantage either in material or structure.

Referring to the physical requirements, if this discussion is to have permanent value, it will lead to the more general use of the best grade of material for our engineering structures and to the reduction in the number of grades of material to the best, and certainly to not more than two. Reference is now made to structural material alone, and not to material for tools and other special purposes. In fact, there may be special cases, even in engineering structures, where it might be advisable for the engineer to specify special grades of material for the several parts. These special cases should be taken up as they occur. The object of this discussion is to settle upon some uniform specification and grades of material for the general and ordinary engineering structures.

Good practice is certainly tending toward a softer metal than what was considered best, even at a very late period; still it does not seem necessary to go as low as 50 000 to 58 000 lbs. ultimate strength to secure a tough, ductile steel of sufficiently high elastic limit to warrant the increased allowable strain per square inch in designing the structures.

Basic open-hearth steel is surely taking its deserved position as a structural material and on equal terms, at least, with acid open-hearth, a position not accorded to it until very recently. When steel first came into use, it was thought desirable to use a higher steel for compression members than that used for tension members; this practice has gradually disappeared, both finished structures and experiments showing no special advantage in the use of the different grades. Such specifications caused confusion in the shops, and the greatest care to see that the various grades of metal were used in the proper members.

The paper does not suggest the adoption of 12 different grades of structural material; the writer is strongly opposed to any such suggestion; one standard grade would seem to be ample, and he would suggest the following:

Open-hearth steel..	Ultimate strength, 57 000 to 65 000 lbs. per square inch.
	Elastic limit not less than 32 000 lbs. per square inch.
	Elongation in 8 ins., 25 per cent.
	Reduction of area, 45 per cent.
	Phosphorus not over 0.06% for acid steel.
	Phosphorus not over 0.04% for basic steel.

The above modified for rivet steel to an ultimate strength of not over 57 000 lbs per square inch.

Mr. Deans

For wide plates..
- Under 42 ins., as above.
- Over 72 ins..
  - Ultimate strength, as above.
  - Elastic limit, as above.
  - Elongation in 8 ins., 22 per cent.
  - Reduction in area, 40 per cent.

Usual bending tests in all cases.

The above will fulfill every ordinary requirement of an engineer. It is a grade that will not be injured by manipulation in the shop. Above certain thicknesses, holes should be drilled or punched and reamed, and sheared edges planed, like wrought iron, for extra thicknesses.

The above test should be determined by test pieces 12 ins. long, $\frac{1}{2}$ sq. in. in cross-section, and not less than $\frac{1}{4}$ in. thick, cut from a finished bar. Most knowledge of steel has been obtained by the experiments made with test pieces of this size, and, unless there is some special reason, it is desirable to retain these dimensions.

Referring to the author's suggestions concerning steel castings, there seems to be no good reason for specifying more than one grade for the castings used in ordinary practice, and the following is suggested:

Acid open-hearth steel.
- Ultimate strength, 57 000 to 67 000 lbs. per square inch.
- Elastic limit, 36 000 lbs. per square inch.
- Elongation in 4 ins., 20 per cent.
- Reduction of area, 25 per cent.
- Phosphorus, below 0.06 per cent.

The above to be determined by a $\frac{3}{4}$-in. round test piece 4 ins. between shoulders, cut from a casting and not annealed.

Regarding the value of the reduction of area of the fractured section as an indication of the quality of the material, it is of the least value of all of the physical requirements. A high reduction may, and often is, obtained in testing material of very irregular quality. The relative values of the physical requirements may be placed in the following order: Elastic limit, elongation, ultimate strength, and reduction of area.

There seems to be no good reason for changing the name of elastic limit to yield point, in discussing and deciding upon specifications for a standard grade of material to be determined by practical testing in the ordinary manner. No confusion has, so far, occurred by the popular use of this term. When used in connection with matters concerning ordinary tests it naturally assumes its peculiar meaning for this case, while the term used in connection with the more elaborate and refined investigations would immediately assume its more exact significance.

Mr. Deans. The recommendation that bending tests be made by pressure, rather than with blows, is a wise suggestion; in no other manner can results be obtained which can properly be compared, and upon which reasonable conclusions can be based.

It certainly seems to be a needless refinement at this day, to specify four grades of wrought iron. One grade with an elastic limit of 26 000 lbs., an ultimate strength of 50 000 lbs., an elongation of 20% in 8 ins., and a reduction in area of 30%, with slight modifications in elongation and reduction for wide plates, would certainly appear to be ample for all requirements.

There is no good reason for specifying a quenching test for steel, to be used in ordinary engineering structures. It is not a condition to which the finished product will be subjected, and, as it does not add to the information obtained by the other proposed physical tests, it appears to be an unnecessary requirement. There is no reason why the percentage of elongation and reduction of area should not be given in a fixed quantity, the same as the elastic limit. They do fluctuate, of course, with the ultimate strength, but this takes care of itself in the specifications given, and by naming fixed requirements, the labor of making a calculation of each test is avoided, which is something to be considered in these busy days.

It may appear to many that the suggestion of fixing upon one standard grade is rather a bold one, and tends to reduce the resources of the engineer. When it is borne in mind that this is only a suggestion for the regular ordinary trade work, the suggestion may appear less unreasonable. For structures of great magnitude, involving peculiar features, and called upon to sustain enormous and variable concentrated loads, machinery subject to severe shocks, tools performing special duties, and in all structures not met with in ordinary practice, an engineer should be free to adopt those requirements necessary to meet special features of design. Any steel manufacturer stands ready to furnish material of any grade from very soft to very hard. For these few and special cases the engineer and buyer must expect to pay the extra cost. It is to throw this extra cost on these special cases and on works of great magnitude and importance where it belongs, and not to increase the expense of all the ordinary and less important structures, that the writer suggests one main standard for ordinary bridge steel, wrought-iron and steel castings.

Mr. Garrison. F. Lynwood Garrison, Assoc. M. Am. Soc. C. E.—The objections to basic Bessemer steel which the author mentions are quite serious ones. The writer does not believe it is possible by this method of manufacture to obtain uniformly a product suitable for structural purposes. In the basic open-hearth furnace, the case is quite different, since it is possible to make quite as good steel by this method as in the ordinary or acid open-hearth furnace. It is not, however, possible to produce

good steel in a basic open-hearth furnace out of bad stock. Of course, the question as to what might be considered bad stock under the circumstances is one open to discussion, and the writer does not care to set up a standard for good or bad in a case of this kind; this is one of the secrets steel-makers must learn by experience. Mr. Garrison.

Exception is to be taken to the indiscriminate use of the word "crystalline" as applied to iron and steel. A crystalline structure is evidently one composed of crystals; a crystal is a solid body, bounded by plane surfaces which assume definite geometrical forms. How often has the author, in his extensive experience with structural steel, detected such crystals in the composition of a fractured surface? There is no intention to criticise the author's phraseology, as he is simply using a common expression, crystalline, applied to a glittering non-fibrous structure, in which, in 99 cases out of 100, it would be impossible to detect the slightest evidence of actual crystallization.

H. H. Campbell, M. Am. Soc. C. E.—Replying to Mr. Henning, the author would say that microscopical work is not among the ordinary systems of testing. The statement that open-hearth steel can be overheated is certainly not open to contradiction. That is a fact which has been known to every one in the business for 20 years, and which was perfectly well known to the author when this paper was presented. It was probably also known by Messrs. Hunt, White and Wailes. Unfortunately it is a fact which has nothing to do with the present subject of mysterious failures, for the fracture of an over-heated piece of steel is not a mysterious failure at all. It remains for Mr. Henning to first prove that these failures, mentioned by Mr. Hunt and others, are due solely to bad heat treatment, and then to prove that open-hearth steel would have failed under the same practice. A mere opinion or statement on this subject is of absolutely no importance when put against the positive facts presented by the authorities mentioned. As to the use of Bessemer steel for rails, it should be mentioned that rails do break much oftener than would be desired in the members of a bridge. The remarks on the shock tests are considered hypercritical. The blow at right angles to the stress seems a very practical application of vibration and "shock," as usually understood. Mr. Campbell.

The statement that it would be no hardship for the manufacturer to make different blooms and ingots for each thickness is absurd. It would be a great hardship and expense. The cost of steel in Germany has nothing to do with the question. The labor conditions of that country, as compared with ours, are known by almost every one. It is true that German manufacturers have not used a sliding scale; it is also true that American manufacturers have not used it, but that is hardly a sufficient argument why it may not be right, or why it may not be advisable, or even why recent developments have not made it almost necessary. The fact that German metallurgists have not yet

Mr. Campbell. adopted such a sliding scale had absolutely no weight with the author in determining the value of the innovation. But it may be well to record that foreign investigators have been holding international conferences for years to establish uniform and standard methods of testing, and that everything cannot be entirely perfect, else this trouble would not be undertaken. As to Professor Marten's experiments showing that soft steel does not offer greater resistance to shock than hard steel, the author will only say that he refuses to accept his conclusions. As to the comparison of steels of different makes, it may be said once for all that the works with which the author is connected makes Bessemer structural material to an extent exceeded by only two or three works in the country; that it makes acid open-hearth steel to an extent equaled by only one works in the country, and that it makes basic open-hearth steel to an extent equaled by only one works in the country. It may reasonably be assumed that the opinions expressed in the paper are unbiased, and that their correctness is limited only by the ability of the author to deduce correct conclusions from ample premises. From this platform of experience, the author would say that Mr. Henning's statement of the inferiority of low acid open-hearth steel is not correct.

Replying to Mr. Lewis, it may be said that there is nothing to prevent an acid open-hearth works from making low-phosphorus material, even when it does not have basic material. The difference in cost of the raw material is not excessive; there is at least one such works now making such material for the open market. The fact that low-phosphorus basic steel will temper, whatever that word means, is indisputable. It is also true that the softest product of any iron or steel process is very materially affected by heating and quenching, but the author has never discovered what this fact has to do with the use of material in a railroad bridge which is not calculated to withstand a conflagration followed by a flood. The statement that the automatic device gives erroneous readings for the elastic limit at moderately high speeds is one of the most important facts or opinions in the entire discussion, and is worthy of careful consideration. The phrase "elastic limit" has become an arbitrary term as part of a trade nomenclature. It denotes the place where the beam drops; and this is the universal meaning in American steel works. A few investigators are trying to introduce an autographic device, and Mr. Lewis now declares that this is just as arbitrary as the present method. The criticism of the low elastic ratios in the specifications is rather unjust. The 47% mentioned is on a $1\frac{1}{4}$-in. plate of a steel which will give 70 000 to 80 000 lbs. ultimate strength and 56 or 58% elastic ratio on a plate or angle of ordinary thickness. All the test pieces cited in the main body of the paper are on usual thicknesses, while all the low elastic ratios given in the specifications will be explained by the thickness of the member and by high ultimate strength.

Mr. Campbell.

Replying to Mr. Wagner on the advisability of a lower limit for phosphorus, the author would consider this a very objectionable innovation. It might result in the rejection of many heats and great loss to the manufacturer, who might often fail to keep between the lower and the upper limit. Such a change would therefore be warranted only by facts showing the bad quality of low phosphorus steel, and such facts are conspicuously absent. The phosphorus in heat No. 10 168 in Table No. 6 is 0.013%, which is probably as low as can be found in any acid steel ever made; but it is hardly probable that any question will be raised about the quality of the metal.

The call from Mr. Lund for a strong steel for building purposes is met by Class IX. The requirements are purposely made very severe, as every precaution must be taken to insure toughness. The suggestion that alloys be devised that will resist corrosion opens up a field which has been practically unexplored. It seems rather unlikely that much can be done in this direction, for the aim of the steel-maker should be to produce the maximum of toughness and strength, while it is left for others to devise some process of coating or painting by which the metal is preserved from destruction. An alloy of iron may be discovered which will not be subject to corrosion, but it is doubtful if it would come under the name of structural steel.

The remarks of Mr. Hunt on the inconsistency of condemning the system of "preliminary tests," and then advocating its use in steel castings, are neither unexpected nor entirely undeserved. The explanation is that the author is not a crank, and that he is willing to use an unsatisfactory system when it will save great expense and delay. Moreover, it must be considered that steel castings do not go through the process of rolling, so that a sample bar may more fairly be used as an index of quality of the metal than in the case of other structural material when it must represent sections of all thicknesses, some of which may have been either overheated or cold finished. The stipulation that basic steel shall not show as high a percentage of phosphorus as acid steel must not be misunderstood. It does not mean that a proper basic slag will inevitably eliminate phosphorus to a low proportion, for the resulting percentage is dependent on the initial content, as well as on the nature of the slag. Almost any stock may be purified to a certain point by suitable slag, but this slag must vary, both in quantity and quality, with the work to be done. A content of 0.08% of phosphorus in basic steel may, therefore, be a result of good practice upon very phosphoritic metal. Neither does this provision concede that phosphorus is more harmful in basic than in acid steel, for there is no proof either that it is or is not. The only point involved is the thoroughly practical and business-like proposition that it is well to require lower phosphorus where it can be easily and economically obtained.

Mr. Campbell. Replying to Mr. Waddell, the author would say that the questions asked are rather beyond the scope of the paper. The terms "soft," "medium" and "hard" are relative and must always remain so, and the nomenclature is entirely unimportant. The decision as to the proper ultimate strength for different purposes is not so secondary a matter, but no dogmatic assertion by the author could possibly settle the question. There will always be differences of opinion, and the manufacturer is willing to make what the engineer thinks best. An opinion is expressed in favor of softer metal, but this is not done to give an advantage to the manufacturer, it being hoped that the paper is not open to the criticism of self-interest. It is true that a softer steel can be made a shade more easily by the basic process than a metal of slightly higher strength, but the greatest economy that could be introduced would be a uniform set of specifications among engineers, so that surplus stock could be applied to other contracts.

The remarks of Messrs. Webster, Howe, Hartshorne and Greiner deal for the most part with matters of opinion on which all metallurgists cannot be expected to agree. The last word is not necessarily any better than the first, and there is no occasion to reiterate any statements previously made. It may be well to say, however, that the author was aware of the paper by Professor Tetmajer, but that he is also aware of a book by Dr. Wedding which gives illustrations of the basic Bessemer practice in Germany a few years ago, and the amount of re-phosphorization and the final content of phosphorus would condemn the steel for the most common purposes. The author is also in possession of other information as to the irregularity of basic Bessemer steel, but the publication of such facts is a very unpleasant occupation. Suffice it to say that no succession of good results from any particular works can wholly justify the general acceptance of basic Bessemer steel as structural material. On the other hand, the author does not suppose that his condemnation can keep this metal out of the market if manufacturers prove, by long experience, that the old and formidable difficulties have been conquered.

The matter of elastic limit, referred to at length by Mr. Webster, has been discussed in replying to Mr. Lewis, and reference was made to the statement that the new method of determination, by the autographic device, is as arbitrary as the drop of the beam. The present method is thoroughly understood, and all contracts and calculations are based on a certain way of finding a certain point. If some other method is to be used, then the steel-maker must be notified beforehand. The meaning of a specification, as now written, is that the elastic limit is taken by the drop of the beam, and any attempt to introduce a new meaning after the agreement is signed is an alteration of the contract. All the elastic limits in the paper under discussion were determined in the regular way, the bars being tested as all structural material has

Mr. Campbell.

been tested at the Pennsylvania Steel Works. Neither the accuracy of the machine nor the methods employed have ever been called in question by any inspector, and Mr. Lewis, Mr. Cunningham and Mr. Webster himself have been among the number who have accepted the results. This fact does not prevent Mr. Webster from advocating any new method of testing, but it certainly sets the seal of his approval upon the statement that the system herein employed is the currently accepted method in common use.

Mr. Goldmark's remarks on the limits of tensile strength refer to small test pieces of uniform size, which can be rolled under uniform conditions. This is a different matter from the present practice of cutting strips from sections of many different sizes.

The remarks of Mr. Seaman on the variation in elastic limit are very important to the engineer, but they do not state anything which was unknown to the author. The specifications are not made to favor anybody or to use up defective material. They are drawn to legally recognize certain actual and existing facts and laws, whereby a thick piece of metal does give a lower elastic ratio than a thin piece when they are rolled under the same conditions. The fact may be new to some engineers and it may be unpleasant, but it is a fact nevertheless.

Mr. Garrison's remarks on basic open-hearth steel are very ambiguous. He states that good steel cannot be made from "bad stock," but qualifies this by saying that he will not attempt to define "bad stock." There is no original sin in any special grade of metal, the grade of badness depending almost entirely on the percentage of phosphorus and sulphur. Given a bath with an average content of 0.08% phosphorus, and it is perfectly immaterial whether this has been produced by the use of one kind of metal holding exactly 0.08% phosphorus, or whether it has been made by a mixture of a large amount of metal containing 0.03% and a small amount containing 1.00 per cent. In the same way on the basic hearth, it matters very little whether a content of 0.05% of phosphorus has been produced by the use of an iron containing 0.10%, together with a rather silicious slag, or whether it has been made from an iron containing 1.00% under the action of a basic slag. Prejudice or opinion has nothing to do with the case. Thousands of tons of good steel are being produced every month out of what always has been called bad stock. The time has gone by to say that this cannot be done. The time has come to see and believe.

In this connection, it may be well to remark that many of the published statements concerning basic steel are wrong, and that some of these statements have been made by those who should know better. A content of 0.08% of phosphorus in basic steel does not necessarily denote bad metallurgical work. It may denote very good practice on bad stock, and redound much more to the credit of the metallurgist than a content of 0.05% when made from a purer metal.

Mr. Campbell. The word "crystallize," to which Mr. Garrison takes exception, might be made the subject of a long dissertation. It is very doubtful whether steel can undergo molecular rearrangement when the metal is at the ordinary temperature of the atmosphere, although it may, by certain conditions of shock and stress, be internally disrupted, so that it shows innumerable planes of cleavage. This structure is called crystalline. It matters not whether the term is or is not correct, for it is in universal use, like "elastic limit," as part of a trade nomenclature and is so used in the paper. It may be in order, moreover, to point out to Mr. Garrison that it is very difficult to be always logically right. An ingot of steel when cooling from a liquid to a solid form arranges itself in coarse crystals. Subsequent heating and rolling reduce the size of these crystals and distort them and weld them to one another, but it is doubtful if they are ever completely destroyed. If this is so, and the author believes he is only stating the commonly accepted theories, how can it be said by Mr. Garrison that "in 99 cases out of 100, it would be impossible to detect the slightest evidence of actual crystallization." Bearing in mind the possibilities of microscopical examination and ultimate chemical analysis, this is a statement which is rather bold, to say the least. Such a comprehensive investigation is not usual, but Mr. Garrison would invite it by his challenge to come down to fundamental facts.

The plan of Mr. Deans, reducing the number of standard grades, is very attractive. There are, however, certain cases where an exceptionally strong steel is indicated, and such cases must be provided for in a complete schedule. Moreover there are some cases where the very best and most reliable metal is obligatory, while there are times when a common metal, like Classes XI and XII, will answer every purpose, and at much less cost. The author would not attempt to limit the range of material at the disposal of the engineer, but has simply tried to give the physical qualities that can be expected from the different kinds of steel. He has not touched upon the question of wrought iron and is therefore at a loss to understand the remarks of Mr. Deans as to the specifications on this material.

The author is in receipt of a communication from Mr. George Bartol, Superintendent of the Otis Steel Company, Cleveland, Ohio, who states that absence in Europe has prevented his taking part in the discussion. He takes exceptions to the conclusions on segregation, being of the opinion that it is a more serious matter than is shown by the records given, but aside from this, says that he can endorse nearly all that is written in the paper. He also hopes that it will "aid in bringing engineers to more rational methods of inspecting and specifying for material, a change which we both know from personal experience is sadly needed." This corroboration of the main points of the paper by Mr. Bartol is worthy of careful consideration as coming from a practical and competing manufacturer.

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THE TOPOGRAPHIC MAP OF THE UNITED STATES.

By HERBERT M. WILSON, M. Am. Soc. C. E.

READ MARCH 20TH, 1895.

It is the purpose of this paper to show something of the progress made and methods employed by the United States Geological Survey on the great topographic survey and atlas of the United States. Space will not be occupied with an argument for the uses, value and cost of topographic maps, nor with a detailed review of the work of other organizations in the making of such maps. These and many kindred subjects are well understood, and were ably treated by Mr. H. G. Ogden, of the United States Coast and Geodetic Survey, in a paper published in the *Transactions* of this Society*. A perusal of that paper will at once show how closely the methods which are employed by the Geological Survey agree with the standard set by the conference of Coast Survey topographers, and how far within the limit of cost set by that conference is the work done by the Geological Survey.

Until within recent years the United States was the most backward of all civilized nations in the making of topographic maps of its territory. Between 1867 and 1882 several independent government surveys were in existence, which mapped large areas of the undeveloped

* Vol. XXX, p. 62.

region west of the Mississippi River. Of these, the Wheeler survey mapped 360 000 sq. miles west of the 100th meridian. The results of this work were published in hachure topographic maps, of which about one-third were on the scale of 4 miles to 1 in., the remaining two-thirds being on the scale of 8 miles to 1 in. The King survey mapped 86 500 sq. miles adjacent to the Central Pacific Railroad, and this was published in 250-ft. contours, on the scale of 4 miles to 1 in. The Powell and Hayden surveys mapped 167 000 sq. miles in Utah and Colorado respectively, which area has been published in 250-ft. contours, on the scale of 4 miles to 1 in.

More recent and of far better quality is the work of the United States Coast and Geodetic Survey and the United States Lake and River Surveys of the Engineer Corps of the United States Army, which organizations have mapped and published, on large scales and in contours, a narrow strip of topography along the entire coast and lake shores, and the Mississippi, Missouri and a few other rivers.

Besides the above a number of states, notably New Hampshire, New Jersey, Pennsylvania, Wisconsin, Kentucky and Minnesota, have made topographic maps of all or portions of their areas, on scales ranging from 1 : 1 600 to 1 : 250 000, some of which are published in contours. The State of Massachusetts has nearly completed a town boundary survey, based on a system of primary triangulation which furnishes numerous control points on every town line. This affords an excellent basis on which to conduct future topographic surveys of any degree of detail.

In addition to the material which is available in map form for the making of topographic maps on various scales, there is in existence a large amount of matter suitable as primary mathematical control, which is the result of triangulation conducted by the Missouri and Mississippi River Commissions, the Gardiner State Survey of New York, the United States Lake Survey, and particularly the United States Coast and Geodetic Survey. These sources render available about 10 000 points, the positions of which have been determined, and though some of the territory covered by them has already been mapped by the Geological Survey, they furnish the foundation upon which to base topographic surveys of a large area of the country. The work of these organizations must be supplemented in many places by additional triangulation, in order to furnish at least two

points for the control of each atlas sheet of the Geological Survey. The positions have been tabulated, and are accessible to the public in Nos. 122 and 123 of the *Bulletins* of the Geological Survey.

Besides this primary horizontal control, there is a vast amount of material available as level bench marks and secondary control, such as railway, canal, city and special private surveys, and the subdivision surveys of the public land system. This material is collected, tabulated and adjusted by the Geological Survey, so that its precise value is well known, and it is thus made available for immediate use. The elevations have been adjusted and reduced to mean sea level and the results published in a "Dictionary of Altitudes," forming *Bulletin* No. 76 of the Geological Survey.

Since 1882 the United States Geological Survey has been actively engaged in making a topographic survey of the country. This work, although primarily inaugurated as a necessary adjunct to a geological survey, has made rapid gains in popular favor, the maps being adapted not only to the needs of the geologist, but to all engineering and economical requirements which their scales will satisfy. The scales at first adopted were 1: 62 500, 1: 125 000 and 1: 250 000, or approximately 1 in. to 1, 2 and 4 miles. The latter scale was abandoned several years ago as being too small. These maps show the surface conformation of the country in contour lines, the intervals between which range from 5 to 250 ft., though contour intervals greater than 100 ft. have been abandoned in recent years.

This topographic survey is being prosecuted simultaneously in all portions of the country, some work having been done in every state and territory. The results are published in atlas sheets of nearly uniform size, bounded by parallels of latitude and meridians of longitude in such manner that the whole may form a continuous and connected atlas of the entire country, regardless of political or natural boundary lines. The atlas sheets upon the 1 mile to 1 in. scale cover 15 minutes each of latitude and longitude, and those upon the 2 miles to 1 in. scale 30 minutes in each direction. Many thousand such sheets will be required to cover the country. Thus far 906 sheets have been surveyed and 775 engraved and published. Of those surveyed 483 are upon a scale of 1: 62 500; 361 upon a scale of 1: 125 000, and 62 upon a scale of 1: 250 000. The accompanying diagram (Fig. 1) shows the area of each State which has already been surveyed.

DIST. OF COL.
RHODE ISLAND
DELAWARE
CONNECTICUT
NEW JERSEY
MASSACHUSETTS
NEW HAMPSHIRE
VERMONT
MARYLAND
WEST VIRGINIA
SOUTH CAROLINA
INDIAN TERY
MAINE
INDIANA
OKLAHOMA
KENTUCKY
OHIO
TENNESSEE
VIRGINIA
PENNSYLVANIA
MISSISSIPPI
LOUISIANA
NEW YORK
ALABAMA
NORTH CAROLINA
ARKANSAS
IOWA
WISCONSIN
ILLINOIS
FLORIDA
MICHIGAN
GEORGIA
WASHINGTON
MISSOURI
NORTH DAKOTA
NEBRASKA
SOUTH DAKOTA
KANSAS
MINNESOTA
IDAHO
UTAH
OREGON
WYOMING
COLORADO
NEVADA
ARIZONA
NEW MEXICO
MONTANA
CALIFORNIA
TEXAS
DIAGRAM
SHOWING THE SURVEYED AND UNSURVEYED AREA
OF EACH
STATE AND TERRITORY
BY U.S. GEOLOGICAL SURVEY.
Area surveyed
Area unsurveyed
10,000 20,000 30,000 40,000 50,000 60,000 70,000 80,000 90,000 100,000 110,000 120,000 130,000 140,000 150,000 160,000 170,000 180,000 190,000 200,000 210,000 220,000 230,000 240,000 250,000 260,000 270,000 280,000 290,000 300,000 310,000 320,000 330,000 340,000 350,000 360,000 370,000 380,000 390,000 400,000 410,000 420,000 430,000 440,000 450,000 460,000 470,000 480,000 490,000 500,000 510,000 520,000 530,000 540,000 550,000 560,000 570,000 580,000 590,000 600,000 610,000 620,000 630,000 640,000 650,000 660,000 670,000 680,000 690,000 700,000 710,000 720,000 730,000 740,000 750,000 760,000 770,000 780,000 790,000 800,000 810,000 820,000 830,000 840,000 850,000 860,000 870,000 880,000 890,000 900,000 910,000 920,000 930,000 940,000 950,000 960,000 970,000 980,000 990,000 1,000,000
AREA IN SQUARE MILES

Fig. 1.

These topographic maps are engraved upon copper, three plates being required for each sheet. Culture, or the work of man, is printed in black; drainage or hydrography in blue; and contours or relief features in brown. All cultural features which are of a public nature, as roads, paths and trails, railways, dams, piers and breakwaters, are shown. Private culture, with the exception of houses, is not represented. This limitation has been made in order to reduce the number of conventional signs to the fewest possible, and because private culture is of little general interest. All streams, fresh and salt marshes, canals and lakes, are shown, the conventions for these being simple and readily intelligible. The surface conformation is shown chiefly in contours, though brown dots are occasionally used on sand or flood plains. Hachures are sometimes employed on exceedingly steep bluffs, and depressed contours, as pot-holes, are indicated by hachuring on the inner side of the contour line and by frequent numbering. The outlines of all timbered areas are mapped in the field and are recorded on the manuscript maps in a uniform green tint, though as yet they are not published on the engraved maps.

The field upon which the Geological Survey is at work is diversified; it comprises broad plains, high and rugged mountains, plateaus and low, rolling hills. Some portions of the country are densely populated, others are almost devoid of settlement, and others are covered with a dense growth of forests. It is by reason of this diversity of conditions that maps of different areas differ in scale, and the difference in natural conditions and scale must result in the employment of different methods of work. In general, it may be said that the more populous portions of the East and of the Pacific Coast are mapped on the larger scales, while less inhabited portions of the country are mapped on the smaller scale; also that the methods of survey which work to advantage in the high mountain regions of the West or in the Appalachian Hills of the East are more or less inapplicable to the flat plains region of the Mississippi Valley and to the forested plains in the northern portion of the country.

From a constructive point of view, a map is a sketch corrected by locations. The making of locations is geometric, that of sketching is artistic. However numerous may be the locations, they form no part of the map itself, but serve only to correct the sketch, the latter supplying the material of the map. The correctness of the map depends

upon, 1, the accuracy of the locations; 2, their number per square inch of map; 3, their distribution, and 4, the quality of the sketching. The first three of these elements define the accuracy of the map, and the greatest accuracy is not always desirable because it is not economical. The highest economy is in the proper subordination of means to ends; therefore the quality of the work should be only such as to insure against errors of sufficient magnitude to appear upon the scale of publication. The above being recognized, it is evidently poor economy to execute triangulation of geodetic refinement for the control of maps upon small scales, and providing the errors of triangulation are not such as are cumulative, the maximum allowable error of location of a point on which no further work depends may be set at $\frac{1}{100}$ in. on the scale of publication. The second condition, the number of locations for the proper control of the sketching, is not easily defined. It depends largely upon the character of the country, and explanation will be made later of the amount of control which the topographers of the Geological Survey have accepted as sufficient for the various scales and regions of their work. The same is true of the third element of accuracy, that of the distribution of locations; while the fourth element, the quality of the sketching, depends wholly upon the artistic skill of the topographer; or, in other words, upon his possession of the topographic sense, which may be described as his ability to see things in their proper relations and his facility in transmitting his impressions to paper. This is by far the most important and difficult requirement to meet, and one which takes a longer apprenticeship on the part of the topographer than all the others combined.

The work involved in making a topographic map comprises four operations: First, the location of the map upon the earth's surface by means of astronomic observation; second, the horizontal location of points, which is usually of three grades of accuracy, primary triangulation or primary control traverse, secondary triangulation, and ordinary traverse for the location of details; third, the measurement of heights, which usually accompanies the horizontal location and may similarly be divided into three classes in accordance with their degree of accuracy; and fourth, the sketching of the map.

Where primary triangulation executed by the United States Coast and Geodetic Survey and equally careful organizations is not already in existence, it becomes necessary to measure and expand a base line

and to execute a system of primary triangulation in sufficient detail to establish at least two points on each atlas sheet. Base lines are measured by the Geological Survey with a steel tape, the length of which is 300 ft., and which is carefully compared at an observed temperature with the standard of the United States Coast and Geodetic Survey, both before entering and after leaving the field. The probable error of several base lines which have been carefully measured with steel tapes by the Geological Survey is so small as to be inappreciable upon the future control work, and is nearly as small as the best results obtained by the old-time expensive system of measuring with base bars. At first compensating bars were used, but experience showed that longer bases, simplifying the expansion and placed at more frequent intervals, were more economic and gave equally good results.

The base having been measured, the astronomic position of one of its ends is determined with the greatest precision. It is not necessary to check the subsequent triangulation by frequent astronomic observations, as they are less accurate than triangulation. Astronomic checks on primary triangulation are therefore introduced only about every 200 to 300 miles. The latitude of the desired position is determined by means of a combination instrument, which is at the same time an astronomic transit and zenith telescope, by Talcott's method, by measuring the differences of zenith distance at the culmination of two stars which culminate on opposite sides of the zenith. The longitude is determined by telegraphic comparison of local time at two stations, the longitude of one of which is known. This involves the determination of the errors of the chronometers used, which is accomplished by the observation of transits of stars across the hairs of transit instruments which are set in the meridians of the places of observation, and recording the same on a chronograph. The initial direction or azimuth of the base line is determined with the theodolite used in triangulation, by measuring the horizontal angle between some close circumpolar star, usually Polaris, and a terrestrial mark. Correction azimuths are also determined about every 100 miles in a system of primary triangulation, and about every 10 to 20 miles in primary traverse.

The work of primary triangulation and its expansion from the base, consists in the selection of stations, in the erection of signals, and in the measurement of angles. Stations are so selected as to give the best shaped triangles and so as to group these into simple quadrilateral,

pentagonal or similar figures. They are also so located as to serve best the needs of the topographer. This requires that they shall offer suitable bases from which to expand the secondary triangulation, and that at least two, preferably three, points, shall fall within each atlas sheet. The signals used differ according to the nature of the country; on the plains a simple signal pole may be erected, or an observing scaffold may be required on which to elevate the theodolite. On bare hills a cairn of rocks may be built; and on wooded hills all the timber may be removed, leaving a signal tree, or sight lines only may be cleared and heliotropes used as signals. Angles are measured by means of theodolites having 8-in. circles, reading by micrometer microscopes to two seconds (see Fig. 2). Great care is taken in the adjustment and placing of the instrument, and in shading it from the sun and sheltering it from the wind. Several series of angles are always observed on each station, both singly and in combinations. Moreover, the telescope is transited at suitable intervals to eliminate eccentricity, and readings are taken on various points of the circle to eliminate errors of graduation.

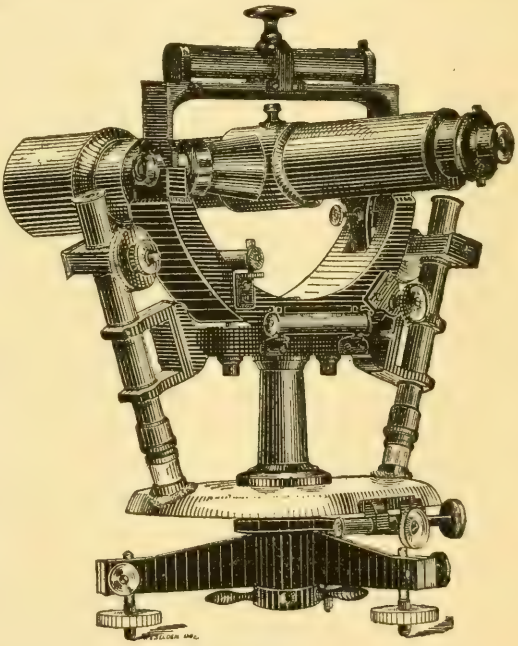


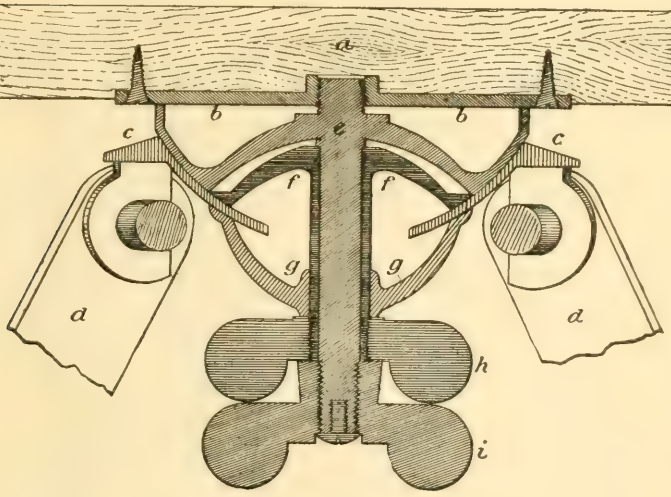
Fig. 2.

In a level country, especially if covered with forests, it is very expensive and sometimes practically impossible to carry on primary triangulation. In such cases the map control is obtained by a system of primary and secondary traverse lines. For primary control, the positions of the initial and terminal points of the traverse are determined by astronomic methods, and in addition to the initial azimuth,

others are observed every 10 or 20 miles in the progress of the work. The directions are measured by an instrument reading to 10 seconds, and the distances by a 300-ft. steel tape. These traverses are run with great care, preferably over a line of railroad in order to get the best grades and alignment; each deflection angle is read at least three times; and the tape is corrected for slope and temperature and reduced to sea-level as in a base measurement. The lines are finally plotted after computing the latitudes and departures, and correcting the courses for convergence of meridians.

The primary triangulation being completed, a preliminary computation of the positions and distances between stations is made in the field

JOHNSON PLANE-TABLE HEAD



a. Plane Table board
b Bearing Plate
c. Tripod Head
d, " Legs
e. Azimuth Cup
f. Upper Level Cup
g. Lower " "
h. Level Clamp
i Azimuth Clamp

FIG. 3.

and these data are furnished the topographer as a basis on which to construct his graphic or plane-table triangulation. From this point forward all of the work is represented on the plane-table sheets, thus requiring the keeping of no cumbersome notes which must be worked

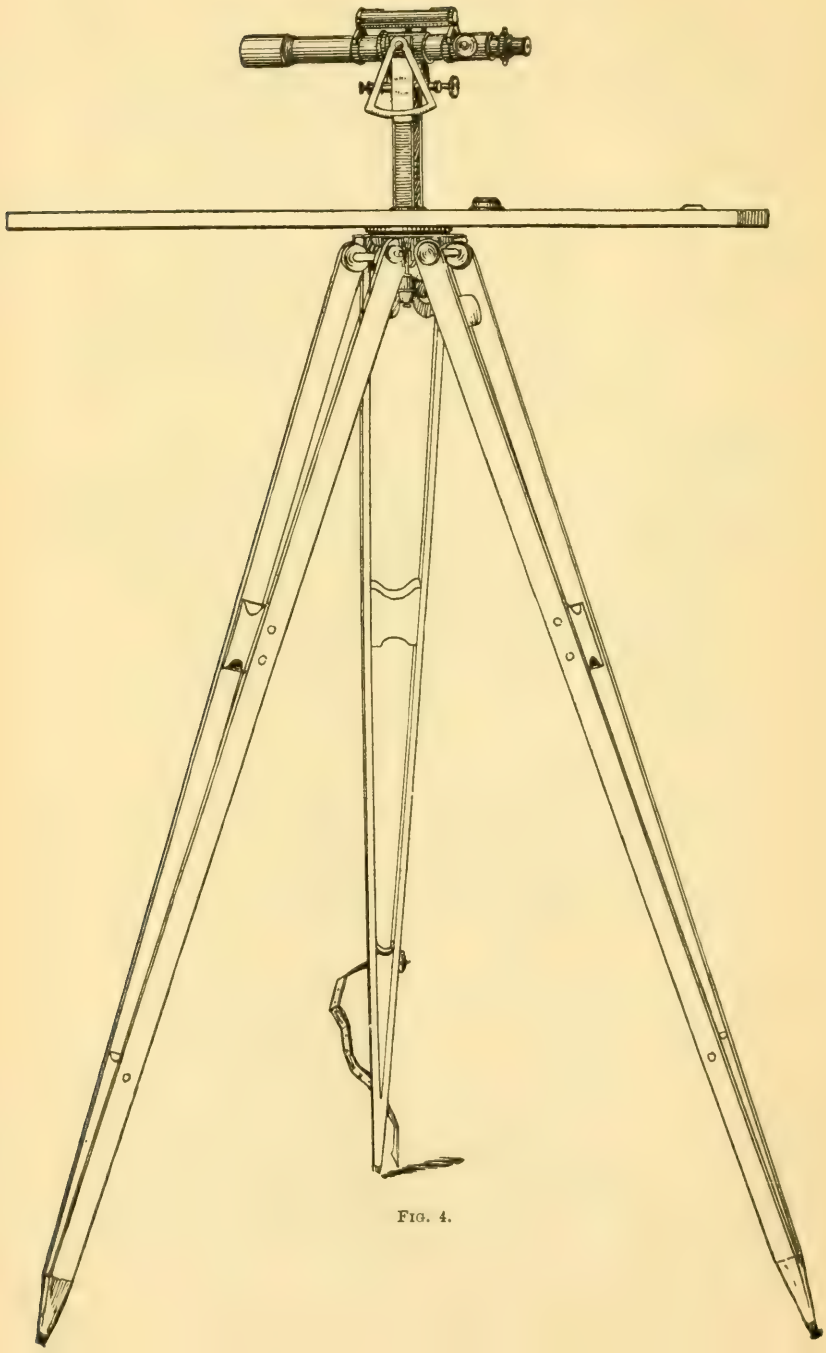


Fig. 4.

up at some future time in the office, while the progress of work from day to day is always observable.

The Johnson plane-table in use in the Geological Survey was designed by one of the topographers of the bureau and is neither so heavy nor so cumbersome as the old-style plane-table, yet it combines the elements of stability, lightness and firmness in a remarkable degree. The peculiarity of this instrument consists in the tripod head (Fig. 3). This is compact and firm, is leveled by a ball-and-socket joint instead of leveling screws and has no tangent motion, being moved by the long lever arm of the board. The alidade used is of the best make and is provided with stadia hairs, a vertical circle reading to minutes, and a ruler 18 to 24 ins. in length (see Fig. 4). Use is not made of large plane-table sheets which have to be rolled up and from which the work has to be carried from one sheet to the other, thus requiring their shifting in the field. Each plane-table sheet is complete within itself, and on it little is recorded other than the graphic triangulation and a little sketching of the immediate summit of the hill occupied. Each of these sheets is of the size of a completed atlas sheet and is made of double-mounted paragon paper, two sheets of paper being backed, one on either side of a piece of stretched muslin, the grain of the paper being crossed to prevent warping.

On taking the field the topographer has, in addition to the triangulation points accurately plotted upon his plane-table sheet, all such data as he has been able to gather from railway surveys, city engineers' offices, county surveyors, or from state or national organizations, so that he is able to make the best use of such material as has been obtained from prior surveys, examining and checking this in the field in order to assure himself whether it is sufficiently correct for adoption. He first makes a hasty reconnoissance of the region to be mapped, which, for an atlas sheet on the 1-mile scale, is about 220 sq. miles in area, and he finds little difficulty in driving over this in from 6 to 10 days, choosing from 15 to 20 suitable plane-table stations and erecting signals thereon. These signals are of the most temporary character, consisting usually of a properly braced rail or pole from 10 to 15 ft. in height, on which a cloth flag about 1 yd. square is fastened. He then proceeds to occupy each of his stations in succession, obtaining intersections upon other chosen stations and upon all such objects as hilltops, lone trees, church steeples, houses, etc., as will probably be seen

and speedily identified from other stations. He also reads and records vertical angles to all these objects, so that when his triangulation is completed—and this process rarely takes longer than a month—his plane-table sheet has located upon it a great many natural and artificial objects, the vertical elevations and the horizontal positions of which are recorded. The number of these positions averages $1\frac{1}{2}$ per square mile or per square inch of map area.

Plate XXXIV is a characteristic illustration of the graphic triangulation executed in the field, on the plane-table board, in making the topographic maps of the Geological Survey. The various sight-lines from one occupied station to another, which are drawn in pencil on the field sheet for obtaining intersections which shall locate the object sighted, are here reproduced in red. The three primary triangulation stations, and those accordingly first occupied by the topographer, Giant Mountain, Hurricane Mountain, and Blueberry Hill, are connected by the heaviest lines. The sight-lines from these to the various occupied stations, and between the latter, are shown in a lighter line. The finest lines are drawn from the various occupied stations to the numerous tertiary locations, which were not occupied by the topographer. Vertical angles were taken to all of these points and their elevations computed within a few feet.

Meanwhile the assistants to the topographer are carefully traversing all roads, for which purpose they use a lighter form of plane-table having no leveling apparatus, on which is a compass needle, the alidade employed being an open-sight ruler 10 ins. long. With these instruments and with the aid of distances measured by an odometer on the wheel of the buggy in which he rides, the assistant traverses every road in the area to be surveyed. He sights to natural objects in the road, usually a sharp bend, orienting his board by means of the compass needle. He sets up his instrument at every other station, taking fore and back sights, and plots frequent lines to the prominent objects about him, as hilltops or other salient features, which he thinks the topographer may locate. In this way he obtains a means of connecting his work with that of the topographer, more especially as he locates all houses on the line of his traverse, and the topographer intersects on many of these. An expert traverseman conducts his work with such skill that, for the scale on which it is plotted—1 mile to 1 in.—scarcely any perceptible error occurs, and

L E W I S
E L I Z A B E T H T O W N
E S S E X
M O R R I S
N O R T H H U D S O N
Little Raven
Bartons Hill
Blueberry Hill

fairly large circuits which tie to the located points of the topographer, close with rarely an error exceeding $\frac{1}{200}$ in. The average traverseman will cover about 12 miles a day. In addition to these road traverses, paced foot traverses are occasionally run between the roads where they are far apart, or where plane-table intersections cannot be obtained, so that on an atlas sheet the amount of located traverse work will average 2.2 miles per square mile or inches per square inch of paper.

Where there are not enough roads to afford sufficient traverse or instrumental control on which to base the sketching, the stadia is used in measuring distances on additional cross-country traverses. In such cases sketching and the determination of elevations by vertical angles are carried on simultaneously with the traversing, as it would be impossible to retrace the lines so run. In extreme cases, as in the Adirondack forests, northern Minnesota and western Washington, where the dense undergrowth precludes the use of the stadia, distances are measured by the engineer's chain. The stadia is also employed in traversing the outlines of bodies of water and in the topographic survey of such regions as southern Louisiana, where the flatness of the slopes requires the use of a 5-ft. contour interval, the elevations in this case being determined by spirit level.

In order to obtain sufficient bench marks on which to base the subsequent and less accurate elevations, an assistant topographer runs a number of spirit-level lines across each sheet, connecting them with some railway or other bench which has been adjusted through from mean sea-level. These spirit-level lines are not usually further apart than 5 miles, the equivalent of two or three being run the length of, and one or two across, each sheet. Thus is furnished also an excellent check to the vertical angle work of the topographer. The average number of spirit and trigonometric level elevations is about 2½ to each square mile or square inch of paper.

As this work progresses the traverses are adjusted to the triangulation locations of the topographer, any little errors which may have occurred in the former being eliminated in the course of this adjustment, and the topographer is now ready to sketch contours, having as a base upon which to do this sketching a sufficient amount of mathematical control.

Plate XXXV is similar to Plate XXXIV in that it shows all the

points located by the graphic plane-table triangulation, but differs from it in being divested of the sight-lines showing how these locations were obtained. In addition, there are brought out in red on this sheet all of the roads or trails over which instrumental traverse lines were run, and by little solid dots locations obtained by intersection from this traverse are shown. The result is a complete exposition in red lines, circles and triangles of the amount of instrumental control on which the sketching is dependent. The elevation of every triangulation location, of whatever degree, is known, as well as its horizontal position, and this aids the topographer in sketching the contours of the higher relief. Elevations obtained along all of the traverse lines, in addition to their horizontal location, afford the topographer mathematical control and data on which to base his sketching of the valley bottoms and the lower relief.

Taking this sketch sheet in his lap, the topographer now drives over every road, and where these are not sufficiently near together, walks in between them and sketches the contours as far as he can safely see them on each side of his path. In performing this operation he starts out from some fixed point, as a road junction or a located house, the elevation of which is known, and setting his aneroid at this elevation, he drives along, recording and marking the points at which the various 20-ft. contours cross his path. The aneroid being an unreliable instrument, he is careful not to drive more than 2 to 4 miles without checking it on a well-determined elevation. He is usually able to do this by connecting with houses or crossing hills, the elevations of which have been previously determined, as above described. If he is not able to so check his aneroid, he hastily sets up his plane table and reads a few vertical angles to hilltops or houses within sight, the elevations of which are known, and with the aid of these angles and the distances, which he can measure on his adjusted sketch sheet, he is able at once to compute the elevation of his position within 3 or 4 ft., and thus to check his aneroid. In this way the sketching of the topography should never be out in elevation more than 20 ft., or one contour interval. In the course of this work the elevations of about 13 points per square mile or per square inch of paper are determined, so it will be readily seen that the sketching of the topography is not likely to be far wrong in elevation. The topographer thus sketches the whole of the area assigned him, not only mapping

E L I Z A B E T H T O W N
E S S E X
M O R R I S
N O R T H H U D S O N
Mt. Pleasant
Mt. Tom
Morristown
Blueberry Hill

the contours, drainage, political boundaries and other topographic features, but also checking the positions of the houses as located by the traverseman.

While the above description of the methods employed applies directly to the work done in the more thickly settled Eastern states, where the scale adopted is 1 mile to 1 in., and the contour interval is 20 ft., it is but slightly modified for use throughout the country on the scale of 2 miles to 1 in. and with contour intervals of 50 or 100 ft.

Extensive use is made, as secondary horizontal control, of the public land surveys in the more level portions of the West, particularly in the region east of the Rocky Mountains. These surveys are first corrected by extending over them a system of primary triangulation or traverse, and connecting this with the corners and crossings of land lines. In some localities this work is not sufficiently trustworthy to be used, even when closely controlled by triangulation. In forest-covered and rough country it is often difficult to find the corners, when it becomes necessary to supplement those discovered by traverses connecting one with the other. In some regions, where the land surveys are of good quality, the corners are easily discoverable. This is the case in regions recently surveyed, or where density of settlement has necessitated the construction of roads on most of the section lines. The work of the topographers is thus reduced to the measurement of heights and sketching, no secondary traverse work or other horizontal control being necessary, as all roads, plats of towns and plans and profiles of railroads are matters of public record in the county offices.

Heights are measured by vertical triangulation based on railway levels and by the aneroid. Vertical angle lines are run on every second or third section line by the topographer, and between these his assistant sketches the topography from aneroid elevations based on the angle lines. In running the latter, distances are measured by the odometer, checked between quarter-section corners, plotted at once and scaled off from the sketch sheet. Vertical angles are read to the platforms of windmills, gables of houses and similar objects, thus dispensing with the use of rods. Sketching goes on coincidently with the measurement of heights.

The average cost of mapping Massachusetts on the scale of 1:62 500 and in 20-ft. contours was a little over $12 per square mile. This was

the first work done by the Geological Survey on this scale. Rhode Island and Connecticut were mapped more carefully and accurately at $10 per square mile. The cost depends largely on the topography of the country. Perhaps the best work yet done by this organization was the mapping of 870 sq. miles about Philadelphia in 1894. Owing to the great amount of culture, such as roads, houses, etc., this work cost $14 per square mile. In New York the best work ranges from $5 in the level country west of Rochester, to $12 in the more broken country east of the Hudson, and even as high as $22 in some parts of the Adirondacks.

In the mountainous regions of the South and in the far West, on the scale of 2 miles to 1 in. and in 100-ft. contours, the work averages $5 per square mile. In the plains country of Dakota, Nebraska, etc., where the public land surveys can be utilized, the cost averages $2 to $3 per square mile. All of the above figures include the office expenses for the winter months when the maps are drawn up.

Something is now to be said of the work of the United States Geological Survey as a whole. The organic law of 1879, creating this survey, as modified in 1882, provides that "The Director of the Geological Survey shall have direction of the Geological Survey and the classification of the public lands, and the examination of the geologic structure and the mineral resources and products of the national domain, and the preparation of a geologic map of the United States." After several years of congressional discussion, this was interpreted to include the making of a topographic map of the entire United States as a base for the mapping of the areal geology.

The scope of the work of the Geological Survey, as modified by legislation from time to time, has come to include the preparation of a topographic base map of the entire United States; the study and mapping of the areal geology upon this base; the examination of the geologic structure and resources of the national domain; the gathering of statistics of mineral production; a study of the artesian and surface water supply of the United States; the mapping of the timbered areas of the country; and, indirectly, the classification of the agricultural value of the public lands.

As in the mapping of the topography of the United States, so in the mapping of the geology. A large amount of valuable detailed work has been done by various state surveys and by the several

government surveys which made reconnoissances west of the Mississippi River. These works were all conducted independently. As the geologists of the Federal Survey had to await the preparation of the base map on which to indicate their areal work, they spent the first 10 years in bringing together the scattered results obtained by all other organizations and individuals into a comprehensive whole, and in studying the nomenclature of, and classifying, the sedimentary and volcanic rocks. The result of this work has been the assembling in systematic form of a great mass of geologic information which has paved the way for the mapping. In consequence, now that the publication of the areal map is begun, it is being pushed forward in a rapid and systematic manner.

This areal geologic map, the final product of the work of the Geological Survey, is presented in geologic folios, each of which covers the area included within a topographic atlas sheet. These folios consist, first, of a brief text descriptive of topographic and geologic maps and the uses to which they may be applied ; next comes a general description of the geology of the region within which is included the folio; then a more detailed description of the geology of the area covered by the folio, which is divided into descriptions of each of the various local formations, an account of the mineral resources, and in some cases an analysis of the economic minerals included within the area. This descriptive material is followed by five maps ; the first is the topographic atlas of the region ; the second, called the areal geologic map, shows the distribution of the overlying rocks within its area; on the third, the economic geologic map, is shown the rocks containing minerals of economic value, these being indicated by distinctive colors ; and on the fourth, or structure section sheet, the underground geology is graphically illustrated, as it is also on the fifth map, which consists of a series of columnar sections.

The scope of the work of the hydrographic division of the Geological Survey is expressed in the statute authorizing it, passed in 1894, which reads : "For gauging the streams and determining the water supply of the United States, including the investigation of underground currents and artesian wells in arid and semi-arid regions." The demand on the survey for information concerning the water resources of the country has increased from year to year. Inquiries come from all sources seeking information relative to artesian water

supply, water-power and water for irrigation. Response to such inquiries requires not only broad knowledge of the topography, geologic structure and meteorologic conditions of the regions involved, but also careful measurement of the catchment areas of the various streams and gaugings through a period of years of their discharge. Such results as have been so far secured were largely incidental to the brief irrigation survey created in 1888. Under the law passed in 1894, however, the work has been systematized and extended as thoroughly as the appropriations will permit. It includes not only an investigation of the conditions in the arid region, but also in the eastern and southern states, where such information is of great value in connection with the utilization of water-power and in the construction of canals and other waterways. A large amount of voluntary assistance is given by local observers who realize the value of the work, and by railway engineers who are sufficiently interested to have their bridge tenders read the river gauges. This co-operation renders much more extensive results possible than with the limited resources at the command of the Survey.

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BACTERIA AND OTHER ORGANISMS IN WATER.

By JOHN W. HILL, M. Am. Soc. C. E.

READ APRIL 17TH, 1895.

WITH DISCUSSION.

In the operation of the filters of the London Water-Works, and indeed of all the European works where filters are used, the test of filtration is based on the number of bacteria of all kinds found in the filtrate. While numerous special examinations have been made of the kinds of bacteria remaining in water after filtration, no continuous tests or standards of efficiency based upon the varieties found have been made so far as the author is aware. Evidently if the bacteria removed are of the harmless kinds, while those that remain are of the pathogenic varieties, no great benefit can be expected from simple filtration of a polluted water. That this is not the case is well attested by the operation of the London filters, which during the past 10 years have been rated upon a bacterial rather than a chemical standard of efficiency, and have reduced the typhoid fever death rate to 14 or 15% of

the rate which prevailed before filtration was practiced. But while the reduction in the numbers of bacteria has been by the London filters from 96 to 99.9% of the original numbers in the water as shown by control plates, the reduction in the typhoid rate has been much less than this, which suggests that of the bacteria still found in the water after very careful filtration, a larger percentage are of the typhoid variety.

Considering the typhoid bacillus as among the smallest known, while many of the harmless kinds are much larger in dimensions, it can be understood how it is possible to have in the filtered water a much larger proportion of the typhoid variety than was found in the original water. In other words, while the general reduction of bacteria in the water has been 96 to nearly 100%, the reduction of the typhoid bacillus probably has been much less than this.

Having a desire to know something about the micro-organisms in the Ohio River water supplied to the city of Cincinnati, and especially upon the effect of the local domestic filters in reducing the numbers of bacteria in the water, a series of careful tests has recently been made to determine generally ;

First.—The kinds of micro-organisms other than bacteria in our local water supply.

Second.—To determine the numbers and to some extent the kinds of bacteria found in the unfiltered and filtered water.

In the examination for the larger micro-organisms, an American microscopic outfit has been used, generally with a 1-in. ocular and 1-in. and ½-in. achromatic objectives. When nice detail of diatoms or desmids has been under examination, a ¼-in. and occasionally either a ⅛ or $\frac{1}{12}$-in. homogeneous immersion objective has been used. However, for the simple determination of kinds and numbers of organisms (other than bacteria) the 1-in. and the ½-in. focal length objectives have been found sufficient.

The water sample for the larger micro-organisms is collected in a small bottle provided with a filter of surgeon's cotton, the bottle connected with a tap by means of a small hose ; and, the tap being set well open, the filtration is accomplished through the cotton filter under low pressure. After the bottle has been in service from 6 to 8 hours it is removed from the tap and the remaining water again passed through a cotton plug in the stem of a 5-in. glass funnel. The cotton filter of

the collecting bottle is soaked and dabbled in the water of the funnel to remove or detach any organisms caught in the cotton filter. After the water has nearly all passed through the cotton plug in the funnel,

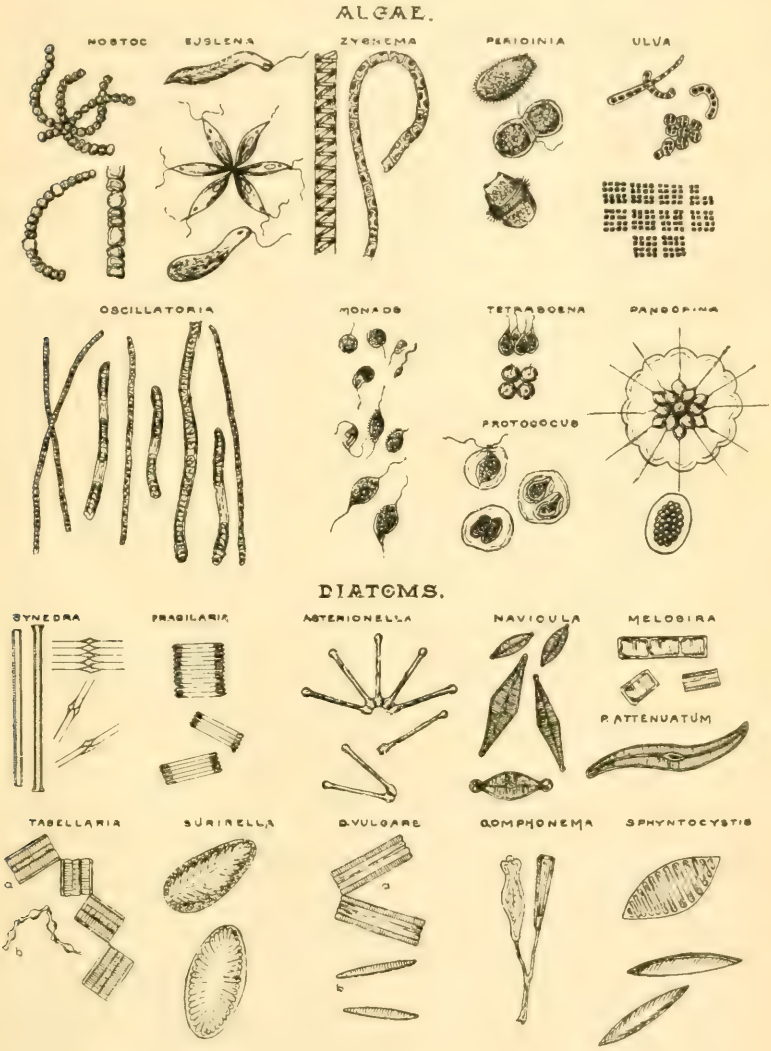

FIG. 1.

small quantities of the sediment are taken up and examined under the microscope. The cell used for this purpose is a plain glass slide

3 x 1 in. in dimensions, to the center of which is cemented a hard rubber ring, about $\frac{1}{32}$ in. high or thick, and giving an internal field of $\frac{5}{8}$ in. diameter. The water sediment is dropped from a pipette into the cell and covered with a $\frac{3}{4}$-in. No. 1 or No. 2 round cover glass.

From the simple microscopic examination of the Ohio River water the following organisms have been found :

Algæ.—(Fig. 1.) Nostoc, Zygnema, Euglena, Peridinium, Ulva, Oscillatoria, Monads, Tetrabœna, Protococcus, Pandorina.

Diatoms.—(Fig. 1.) Synedra, Fragilaria, Asterionella, Navicula, Melosira, P. attenuatum, Tabellaria, Surirella, D. vulgare, Gomphonema, Sphyntocystis.

Desmids.—(Fig. 2.) Pediastrum, Scenedesemus, Cosmarium, Staurastrum, D. Swartzii, Docidicum baculum, Spirotænia.

Infusoria.—(Fig. 2.) Keronia, Enchelia.

Rhizopods.—(Fig. 2.) Difflugia, Amœba, Euglypha, Actinophrys sol.

Rotifers.—(Fig. 2.) Hydatina senta, Monostyla quadridentata, Brachionus amphiceros.

Entomostraca.—(Fig. 2.) Bosmina cyclops, Daphnia pulex.

Spongilla.—(Fig. 2.) S. Lacustris, S. Fluviatilis.

Nematods.—(Fig. 2.) Anguillula fluviatilis.

Miscellaneous.—(Fig. 2.) Ova of Ascaris dentata, scales of insects, cotton fibers, shaft of straw, tip of feathers, amorphous matter.

Some of these organisms like Nostoc, Asterionella formosa, Oscillatoria and other of the algæ, have been charged with the production of bad tastes and odors when found in impounded waters, but such objection to their presence has never been noted in connection with the Ohio River water. Possibly the numbers were not sufficient to affect the large volume of water usually flowing in the river, or it may be that the opportunities for growth and decay are less in streams than in quiescent reservoirs.

The most objectionable, or at least the most repulsive, elements in water are the masses of albuminous matter in process of disintegration, and the infusoria and other organisms which are seen feasting on this matter. Having the amorphous or indescribable matter which may come from sewage and other organic sources, it is proper to have the infusoria, rhizopods and other primitive organisms to assimilate it, and render it less offensive to good taste, as well as less inimical to

health. But to find the slimy, crawling, leechlike creatures traveling around in water which is offered one for drinking purposes cannot be

FIG. 2.

regarded as a recommendation for such water. Among these lowly organisms found in a polluted water are some in which the differentia-

tion between the animal and vegetable growths can be accomplished only by chemical tests upon the protoplasmic substance, many of the protophyta or vegetable products having the appearance and motion of animals, and many of the protozoa or animal growths having the appearance of vegetables with no apparent motion at all, or often seen at rest and indicating a state of complete repose.

In making tests for the bacteria in water, the method pursued by the author has been to collect the water in carefully sterilized 2-oz. glass-stoppered bottles, enclosed in small sterilized tin canisters, and to inoculate the gelatine or agar plates with one or more drops of the water under examination, and then, after mixing the water and melted media, heating the mouth of the tube, and singeing the cotton plug to destroy any chance organisms, to pour the solution of nutrient media and water into a sterilized Petri dish. Usually from 6 to 10 cu. cm. of gelatine or agar is used, and the number of drops of water from a sterilized pipette depends upon the extent of pollution, or rather the number of bacteria suspected in the water. From a very polluted water, one drop, or $\frac{1}{15}$ cu. cm., is too much, the number of bacteria present being so great as to be innumerable by the Wolffhugel method, and absorbing the nutrient media so completely as to prevent the growth of some varieties. In such cases, after shaking the bottle containing the sample of water under investigation, it is customary to dilute this several times with sterilized distilled water and multiply the actual count of bacteria accordingly. With comparatively pure natural waters (which are, unfortunately, rarely found) $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$ or 1 cu. cm. is used for inoculation purposes; a single drop from one of the ordinary dropping tubes or pipettes with rubber tops may contain from $\frac{1}{15}$ to $\frac{1}{24}$ cu. cm., and after the use of one of these it must be measured to determine the proportion of a cubic centimeter used in the inoculation. The period of incubation which has been allowed is five days at room temperature, except with filtered waters, when the time has been extended from 10 days to two weeks or more. The growth of bacteria is rapid in polluted water, and if liquefying organisms are present, as they generally have been in the waters experimented with, the count must not be delayed beyond four or five days or the liquefiers will spread over the plate and obscure some of the non-liquefying colonies. It is a noticeable fact in the author's experience, that plates inoculated with water from the best type of filters require more

time for the incubation of the colonies of bacteria than those with unfiltered water. Thus the germs left in the water after filtration grow at a slower rate than many that are in the water before filtration. From which it would follow that in counts of plates of unfiltered water at the end of a few days, some bacteria are very liable to be overlooked because they have not grown. This may have no significance, but it is well known that the typhoid bacillus is comparatively a slow growing germ, and might be obscured on an ordinary growing plate. While the growth of many of the bacteria is much slower at room temperature subject to variations, than in the incubator where the temperature is maintained quite constant, still the rapid-growing liquefying germs in the incubator are frequently seen to spread and obliterate the non-liquefiers, and destroy the germs of slow growth altogether.

From the bacterial examination of water supplied through the public mains of Cincinnati, the following results have been obtained.

Samples of water freshly plated :

1894. Plate inoculated.	Plate Counted.	Colonies of bacteria per cubic centimeter of sample.
July 14th,	July 18th,	9 570 (*a*)
July 14th,	July 18th,	7 665 (*a*)

Same sample of water tested 10 days after collection in sterilized bottle:

July 24th,	July 29th,	163 000 (*a*)
July 24th,	July 29th,	94 050 (*a*)

Sample of water freshly plated:

August 1st,	August 6th,	1 680 (*a*)
October 5th,	October 10th,	1 872 (*b*)
October 5th,	October 10th,	5 820 (*a*)
October 24th,	October 29th,	1 760 (*b*)
November 2d,	November 7th,	2 674 (*a*)

(*a*) Gelatine, 10% solution, water in bottle shaken.
(*b*) Agar, 1% solution, water in bottle shaken.

Water from the local filters has given the following results. Pasteur filter in perfect condition :

1894. Plate inoculated.	Plate Counted.	Colonies of bacteria per cubic centimeter of sample.
July 16th,	July 23d,	52 (*a*)
October 5th,	October 10th,	2 (*a*)
October 5th,	October 15th,	4 (*a*)
October 5th,	October 15th,	4 (*b*)

Pasteur filter in drug store furnishing water for prescriptions:

November 6th,	November 25th,	4 (*a*)
November 6th,	November 25th,	8 (*a*)

Pasteur filter in ordinary condition:

October 5th,	October 10th,	974 (*a*)
October 5th,	October 10th,	1 536 (*a*)
October 5th,	October 10th,	580 (*b*)

Pasteur filter, well taken care of in one of the leading hotels, supposed to be sterilized every two or three days:

October 24th,	October 29th,	436 (*b*)
October 24th,	October 29th,	180 (*c*)
October 24th,	October 29th,	209 (*c*)

Derham's stone germ-proof filter, in a popular restaurant:

August 27th,	September 2d,	19 035 (*c*)
August 27th,	September 2d,	48 600 (*a*)

Freudenrich* has made some experiments with the Pasteur filter to determine the sterility of the filtrate at different dates after sterilization of the tubes, and for different temperatures of the room in which the filters were kept, and finds that at a temperature of 35° Cent. the filter delivered sterile water at the end of six days, while at a temperature of 22° Cent. the filtrate in some cases was, and in other cases was not, sterile at the end of 10 days. The cause of one filter furnishing sterile water and another operated under the same conditions giving a filtrate containing bacteria, is explained by the investigator as being due to the difference in the density or porosity of the

(*a*) Gelatine, 10% solution, water in bottle shaken.
(*b*) Agar, 1% solution, water in bottle shaken.
(*c*) Gelatine, 10% solution, water in bottle not shaken.
* *Centralblatt fur Bacteriologie*, Vol. XII, 1892, p. 240.

tubes, and to differences in the micro-organisms present in the water at different times.

It has been the author's experience with water from filters of this type that they never furnish absolutely sterile water; for upon a series of plates inoculated with such water, while some may remain sterile for several days, in due time they will develop one or more colonies. An entirely sterile plate he has never met with. Professor Percy Frankland, in discussing this filter, says: "It must be regarded, therefore, still as an open question whether pathogenic organisms, such as typhoid bacilli, can or cannot grow through the pores of the Chamberland (Pasteur) filter, and until this question has been answered in the negative, it is obvious that in using these cylinders they should be frequently cleaned and sterilized." Not having the details of the Freudenrich tests, it is impossible to compare the results from abroad with those obtained here. Tests of Pasteur filters in such condition as they are found in hotels and restaurants have given from 180 to 1 500 bacteria per cubic centimeter, and the low counts of two to four bacteria per cubic centimeter have been obtained from tubes not previously used.

During August, 1894, some bacterial tests were made of the water supplied to Jersey City, N. J., with the following results:

Plates inoculated.	Plates Counted.	Bacteria per cubic centimeter.
August 19th,	August 24th,	1 560 (*c*)
August 19th,	August 24th,	1 575 (*d*)
August 19th,	August 24th,	9 918 (*a*)
August 19th,	August 24th,	9 390 (*b*)

Water from a well-known sand filter found in one of the Jersey City hotels:

August 19th,	August 24th,	8 295 (*b*)

A sample of Jersey City water gave the following results:

August 14th,	August 21st,	1 200 (*d*)
August 14th,	September 1st,	125 000 (*d*)

Note the last result, a count of the plate after one week's inoculation gave on agar 1 200 colonies. The plate was then returned to the moist chamber, and at the expiration of 18 days from the date of planting, it showed, when counted, an increase of over 100 to 1 of the

(*a*) Gelatine, 10% solution, water in bottle shaken.
(*b*) Agar, 1% solution, water in bottle shaken.
(*c*) Gelatine, 10% solution, water in bottle not shaken.
(*d*) Agar, 1% solution, water in bottle not shaken.

bacteria found at the end of seven days. A portion of this latter number probably came from the air of the room in which the work was conducted, but from a number of tests at different times on air plates, the rate at which the air germs and molds fall into a 3½-in. Petri dish is from three to four per minute of exposure, and as the exposure of a growing plate to contamination by air germs is carefully limited to the least possible time, but few of the 125 000 colonies of bacteria in this case could have gravitated from the air into the dish.

Professor Percy Frankland* has made many bacterial tests of the waters of the Rivers Thames and Lea before filtration, with the following results for the same months as were embraced in the author's tests of water from the Ohio River:

RIVER THAMES—BACTERIA PER CUBIC CENTIMETER,

MONTH.	1886.	1887.	1888.
July	3 000	2 500	1 070
August	6 100	7 200	3 000
September	8 400	16 700	1 740
October	8 600	6 700	1 130
November	56 000	81 000	11 700

RIVER LEA.—BACTERIA PER CUBIC CENTIMETER.

MONTH.	1886.	1887.	1888.
July	5 400	12 300	2 190
August	4 300	5 300	2 000
September	3 700	9 200	1 670
October	6 400	7 600	2 310
November	12 700	27 000	57 500

Later bacterial tests of waters from the same sources by Dr. E. Frankland† have been made as follows, taken for the same month as before:

RIVER THAMES.—BACTERIA PER CUBIC CENTIMETER.

MONTH.	1892.	1893.
July	2 263	2 132
August	2 421	1 895
September	947	1 158
October	2 316	13 790
November	1 868	1 789

* "Micro-Organisms in Water," by P. and G. C. Frankland, 1894.

† Annual Summary of Vital Statistics, in London, etc., 1892-93.

River Lea.—Bacteria per Cubic Centimeter.

Month.	1892.	1893.
July	631	8 816
August	631	6 658
September	737	3 658
October	737	5 368
November	3 183	8 026

The agreement of the numbers of bacteria in the water of the River Lea upon two occasions for two consecutive months is very remarkable, and suggests a bacterial condition of the water which the author has never before noticed in any experiments.

A comparison of the bacterial condition of the raw water supply of London for the years 1892–93, with the earlier results obtained by Professor Percy Frankland, shows a very marked improvement in the quality of the water.

The general standard of bacterial quality of the filtered London water is 100 per cubic centimeter, but according to Dr. Frankland, there would be no difficulty for some of the companies to keep the number under 50 per cubic centimeter in the filtered water. The advantage of frequent bacterial examinations of a water supply is well stated by this authority* in the following quotation :

"The vast majority of microbes found in potable waters are, as far as is known, entirely harmless, and although pathogenic germs have been discovered amongst these, it has only been on rare occasions. They have never been observed in any water supplied to London, but it must not, on this account, be concluded they are never present. * * * A glass of water might contain two or three typhoid germs, and yet it would only be by the merest chance that one of them would be included in the five-hundredth part of the glassful (half a cubic centimeter) taken for bacteriological examination."

Speaking, then, of the work of the filters of the West Middlesex Company, which were reducing the numbers of bacteria in water by 99.83%, and of the Lambeth Company, which were filtering out 98.76% of the bacteria originally in the Thames water, he says :

"In this enormous reduction there is obviously a considerable, though by no means absolute, guarantee that pathogenic organisms, if present, would disappear with the crowd. Nevertheless, it is only by the rejection for dietetic purposes of water polluted by ex-

* Annual Summary of Vital Statistics, in London, etc., 1891, p. 51.

crementatious matters that immunity from water-borne zymotic poisons can be secured."

It is not practicable to reject water containing sewage pollution in all cases of a public water supply, but it is practicable to sterilize all such waters before they are used for dietetic purposes.

Many tests of the waters of the River Spree and Lake Tegel supplying the city of Berlin, have been made by Plagge and Proskauer*, with the following results for the year 1885:

BACTERIA.—PER CUBIC CENTIMETER.

MONTH.	RIVER SPREE.	LAKE TEGEL.
July	2 640	1 500
	110 740	13 220
August	1 800	179
	11 900	4 410
September	960	111
	9 200	1 220
October	1 204	160
	4 840	519
November	2 520	60
	31 500	251

The sewage pollution of the Thames River, above Hampton Court, and of the River Lea, above New River cut, or of the River Spree, above Berlin, is probably much less than that of the Ohio River above Cincinnati; here the river is said to carry the sewage of 1 500 000 people before it passes the city intake, and while the bacterial condition may appear to be better than that of London (1886–1888) and the Berlin supply from the River Spree (1885), there can be no doubt of the greater probability of finding pathogenic germs at all times in our water supply. Few consider that our water supplies when taken from the Great Lakes and rivers carry into our households the refuse from hospitals, asylums and many other public institutions where infectious disease generally is prevailing. Of such institutions there are many on the Ohio River and its tributaries above Cincinnati.

The great variation in the numbers of bacteria counted from the same source on different dates of the same month, or upon a series of plates all inoculated in the same manner at the same time, has frequently been noted, and is probably due primarily to the lack of

* Zeitschrift für Hygiene, Vol. II, 1887, p. 401.

uniformity in the distribution of the bacteria throughout the water sample, and somewhat to the nutrient properties of the media employed and temperature of growth.

When the nutrient media are from the same solution for a series of three or more plates, and the conditions in other respects the same, the author has frequently found a great difference in the number of bacteria from successive drops of water from the same sample, which can be reconciled only upon the theory of a lack of uniform distribution of the organisms in the water sample. It is well known in the case of a water sample allowed to stand for a few minutes, that the number of organisms varies considerably with the depth at which they are taken by the dropping tube, the smaller number being found near the surface of the water, and the larger number at the bottom. To avoid an error due to depth of water when the sample is taken up for inoculation of the nutrient media, it is customary to shake the bottle thoroughly before it is opened and the sample taken, to distribute as well as possible the organisms throughout the whole volume of water.

The number of bacteria per cubic centimeter of a water sample also depends upon how the inoculation is made; whether the water is taken from the collecting bottle and quickly dropped into the gelatine, or is given time to permit of the bacteria settling to the point of the pipette before inoculating the tube. A test for the effect of gravitation of the bacteria after the sample of water has been taken up in the dropping tube is given below:

Plate I.—Water taken from the beaker into the tube, and a few minutes allowed for the bacteria to settle to the point of the tube before the inoculation was made.

Plate II.—Inoculation quickly made after the sample of water was taken into the dropping tube.

Plate III.—Same as 2.

Water from Domestic Cistern.

Plate I.—Bacteria per cubic centimeter	1 330
Plate II.—Bacteria per cubic centimeter	460
Plate III.—Bacteria per cubic centimeter	480

In regard to the use of round numbers in stating the count of a plate containing a growth of water bacteria, it is proper to remark that

in most cases great exactness in the count is not necessary. It is quite immaterial whether the count of a given plate is 1 500 or 2 000 bacteria per cubic centimeter, because either number is many times in excess of the standard now set for potable waters. Moreover, those who have had experience in counting the growth of a large number of bacteria by means of the ruled glass plate set over or under a deep Petri dish can well understand how easy it is to under or over count the number by a small percentage.

The question is sometimes asked of what advantage is the knowledge of numbers of bacteria in water? To which the answer may be given that numbers indicate sewage pollution. Large numbers have not been found in waters from exceptional sources, as springs, deep wells, hail, and freshly fallen rain and snow, and the numbers increase per unit of volume when we approach those sources known to be sewage polluted until we reach veritable sewage, when the numbers become uncountable excepting by such a large dilution of the sample as to leave the resultant count a broad guess as to actual numbers. Taking the extremes of deep well water with very few bacteria, and sewage with millions per cubic centimeter, we can readily conceive of a tolerably intimate connection of numbers and organic pollution in a source of water supply, and in the absence of proof to the contrary it is proper to infer that in a water known to be open to sewage contamination and showing large numbers of bacteria it is very possible that pathogenic germs are among the lot.

Apollinaris water is regarded everywhere as the "Queen of Table Waters," and is in such demand for drinking purposes that in our country it commands a price of from 75 cents to $1 per gallon, a very high price indeed for even an absolutely pure drinking water. Recognizing the extent to which this water is used for drinking purposes and having a curiosity to know more about it, the author recently made three plate cultivations on gelatine from a fresh unopened bottle of Apollinaris water, with the following results:

Plate I.....	1 984	bacteria per cubic centimeter.
Plate II.....	1 728	" "
Plate III.....	2 112	" "

The standard for the filtered water from the London Water-Works has been stated as 100 bacteria per cubic centimeter, and the number

has often been so low as 18–20 per cubic centimeter, and upon one occasion absolutely sterile water was reported.*

Before inoculating the gelatine with the Apollinaris water, great care was taken to heat the neck of the bottle and scorch the cork before the wires holding it in the bottle were cut; and everything being in readiness, the inoculations were quickly made.

While the number of germs in the Apollinaris may be more or less (probably less by the inhibiting action on the growth of bacteria of the "carbonic acid gas" in the water) than when originally bottled, still this is the condition in which we drink it when taken from freshly opened bottles. Among the organisms found on the gelatine plates was *Chalothrix dichotoma*, which is usually held to indicate the presence of considerable organic matter in water. The water reacted quite alkaline, and it would therefore be good breeding material for most water bacteria, especially the cholera bacillus.

The spring from which this well-known water is obtained is located in the valley of the Ahr, in Rhenish Prussia, and is said to have a capacity of 27 400 U. S. galls. per day, while the present output of bottled water amounts to 12 330 galls. per day. A number of chemical tests have been made of Apollinaris, but from the information available it seems not to have been tested for bacterial life before.

From tests of water samples taken from the Ohio River at Cincinnati and other sources, a few germs have been carefully differentiated as given in the following list.

In some cases there is doubt in the author's mind of the germs being correctly designated, but the slight difference between the appearance under the microscope and otherwise of a number of the water bacteria which have been described leaves room for suspicion that some of the descriptions of independent and different germs are really of varieties of the same growth, and while several of the germs mentioned below may be totally new growths, as they have sometimes appeared to be, the author prefers to fit them as well as possible to the descriptions given in the old lists of bacteria found in various waters. Unless the exact culture methods of the original investigators are fol-

* Annual Summary of Vital Statistics for London, etc., 1893. Chelsea Company for February, p. 55. The author is disposed to take this statement with some allowance. While of a series of three or more dishes inoculated at the same time from the same sample of filtered water, some have failed to develop any growth within the customary five days, as an average of all the dishes he has never had a wholly negative result.

lowed, certain differences in color, form and luxuriance of growth and microscopic appearance of the bacteria will occur, which renders the differentiation of the growth by any of the existing lists at times a very perplexing task. However, if in all cases the differentiation be carried far enough to determine non-pathogenic properties, from a water analyst's standpoint it is immaterial what the precise designation of the germs may be.

Bacteria Found in the Ohio River Water.

Bacillus hyalinus.—Originally described by Mr. Edwin O. Jordan, Report of the Massachusetts State Board of Health, 1890. From the sand of a tank used for filtering sewage.*†

Bacillus der rothe.—Originally described by Lustig, "Diagnostik der Bacterien des Wassers," 1893. Found on one occasion in river water.*

Bacillus liquefaciens.—Originally described by Eisenberg, "Bacteriological Diagnosis," 1887. Frequently found in water.* † ‡

Bacillus fulvus.—Originally described by Zimmerman, "Die Bacterien unserer Trink und Nutzwasser, inbesondre des Wassers der Chemnitz Wasserleitung," 1890. Found in Chemnitz water supply.*†

Bacillus figurans.—Originally described by Dr. V. C. Vaughan, in "A Bacteriological Study of Drinking Waters," 1892. Found in several Michigan waters.†

Bacillus violaceus.—Originally described by Zopf, *vide* "Die Mikro-organismen," 1886. Found in water and hail.* † ‡

Bacillus subtilis.—Originally described by Ehrenberg. Found in air, water, fæces and putrid liquids.* † ‡

Micrococcus carneus.—Originally described by Zimmerman, in an examination of the Chemnitz water supply mentioned above.* †

Micrococcus rosettaceus.—Originally described by Zimmerman, in an examination of the Chemnitz water supply mentioned above.* †

Micrococcus aquatilis.—Originally described by Meade Bolton, "Zeitschrift für Hygiene," Vol. I, 1886. Very frequently found in water.* †

Micrococcus cereus albus.—Originally described by Passet (see below).* †

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* Micro-Organisms in Water, by Percy and G. C. Frankland, 1894.

† Manual of Bacteriology, by Dr. George M. Sternberg, 1892.

‡ Bacteriological Diagnosis, by Dr. James Eisenberg, Vienna, 1887.

Micrococcus citreus.—Originally described by Adametz, "Die Bacterien der Nutz und Trinkwasser," 1888. Found in water.*

Vibrio aureus.—Originally described by Weibel, "Centralblatt für Bacteriologie," Vol. IV, 1888. Found in a sample of sewer mud.* †

Bacteria Found in Apollinaris Water.

Micrococcus cereus albus.—Originally described by Passet, "Fortschritte d. Medicin," 1885, No. 2. Found in pus by Passet, and in water by Tils; occurs also in air.* †

Sarcina candida.—Originally described by Lindner, "Die Sarcinieorganismen der Garungsgewerbe," Berlin, 1888. Found in the water supply of a brewery; occurs also in the air.* †

Cladothrix dichotoma.—Originally described by Cohn. Present in large numbers in fresh and brackish waters, and in both running and stagnant water, especially in the latter when rich in organic material.* †

Bacteria Found in Cistern Water.

Bacillus aquatilis.—Originally described by Lustig, "Diagnostik der Bacterien des Wassers," 1893. Found frequently in various waters.* †

Bacillus aureus.—Originally described by Adametz, "Die Bacterien des Nutz und Trink Wassers," Vienna, 1888. Found in water and on the skin of eczema patients.* †

Bacillus fluorescens liquefaciens.—Originally described by Flugge, "Die Mikro-organismen," 1886. Very often found in water.* †

Micrococcus aurantiacus.—Originally described by Schroeter, "Beitrage z. Biologie der Pflanzen," 1870. Found in water and in the air.* †

Incidentally the following organisms have been found in the air of the room where the work has been conducted. Frequent tests have been made upon the air, to arrive at possible contaminations upon plates and in test tubes, when of necessity these are exposed to the atmosphere.

Bacillus ramosus.—Originally described by Percy and G. C. Frankland, "Zeitschrifte für Hygiene," Vol. VI, 1889. Found in the soil and in water (heretofore).* †

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* Micro-Organisms in Water, by Percy and G. C. Frankland, 1894.

† Manual of Bacteriology, by Dr. George M. Sternberg, 1892.

Micrococcus versicolor.— Originally described by Flugge, "Die Mikro-organismen," 1886. Frequently found in the air; also in water.* † ‡

Micrococcus candicans.— Originally described by Flugge, "Die Mikro-organismen," 1886. Found in air and water.* †

Micrococcus carneus.—Mentioned above as having been found in the Ohio River water.* †

Micrococcus flavus liquefaciens.—Originally described by Flugge, "Die Mikro-organismen," 1886. Found in water and air.* †

Micrococcus cerasinus siccus.—Originally described by List, "Die Bacterien des Nutz und Trink Wassers," Vienna, 1888. Found in water (heretofore).*

Sarcina lutea.—Originally described by Schroeter, in "Beiträge z. Biologie der Pflanzen," Vol. I. Found in air and water.* † ‡

None of these bacteria are said to have pathogenic properties.

A careful investigation of the subject of bacteria in a water supply seems to lead to the following conclusion: If the source of water supply is beyond the reach of sewage contamination, the probability of finding pathogenic bacteria in such water is very remote, because the bacteria of which we stand in awe, the typhoid and cholera germs, are not indigenous to water, but are always imported into it, generally from sewage sources. Upon the other hand, if the water source be exposed to sewage contamination, and bacteria are found in such water it should promptly be condemned for drinking purposes. It is a singular fact that in several instances where pathogenic bacteria have been found in water (excepting, of course, sewage effluents), the number of bacteria of all kinds per unit of volume of the water is small. Thus, Dr. Vaughan,§ in a well water containing so few as 20 bacteria per cubic centimeter, has found germs fatal to the lower animals, and presumed from collateral evidence to be pathogenic to man, while lake water from the same locality containing 5 300 bacteria per cubic centimeter was harmless when inoculated into the lower animals. Again, artesian well water containing only 10 germs per cubic centimeter was fatal to the lower animals, while river water from an adjoining county containing 3 000 bacteria per cubic centimeter was harmless.

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* Micro-Organisms in Water, by Percy and G. C. Frankland, 1894.

† Manual of Bacteriology, by Dr. George M. Sternberg, 1892.

‡ Bacteriological Diagnosis, by Dr. James Eisenberg, Vienna, 1887.

§ A Bacterial Study of Drinking Water, by Dr. V. C. Vaughan, Ann Arbor, 1892.

In some tests of water samples for the city of Rochester, N. Y., made several years ago by Dr. H. C. Ernst, of Harvard,* the one which contained the fewest bacteria gave the largest variety, and was the only sample said to contain the typhoid bacillus. A statement, therefore, that by a certain process of purification the number of bacteria in a given water has been reduced from 1 000 to 4 per cubic centimeter is not convincing proof of the capacity of such process to eliminate disease germs, because four bacteria per cubic centimeter mean upwards of 1 000 in a single tumbler of water, and among 1 000 bacteria left in any sewage-polluted water there is a possibility that some may be pathogenic germs, provided such were in the water before treatment.

In one aspect of the problem, the number of bacteria in a water sample is of little consequence, because, if it is certain that there are no pathogenic organisms among the lot, no harm can possibly result from the swallowing of a few thousand or even a few million of bacteria with a glass of water. For, even if we drink absolutely sterile water, thousands of harmless bacteria from the buccal cavities are washed into the stomach with every glassful (Sternberg). The condition, however, is materially altered when we realize that in waters which have been polluted with sewage there are always grounds for a strong presumption that among the swarms of bacteria some are possessed of pathogenic properties, and in drinking such waters we are liable, in fact bound, to imbibe some of them.

In making a series of culture plates from a particular water sample the author has noticed (especially when the inoculations have been made with one or a few drops of water) that certain organisms will be found on one plate and not be found on the others, showing that while *B. Subtilis*, for instance, was present in one sample drop, it was not present in all, from which the inference is drawn that only from many tests at different times of the same water can the kinds of bacteria in such water be properly stated. One reason why pathogenic germs have been found in waters containing comparatively few bacteria per cubic centimeter, and not found in samples showing much larger numbers, is because of the easier differentiation of the kinds of bacteria when the numbers are low and the great difficulty of differentiation of all

* Annual Report of Executive Board, City of Rochester, N. Y., April, 1890.

the kinds when the numbers are high, and also in the crowding out and total obscuration of many kinds (some of which may be pathogenic) in a cultivation containing many liquefying colonies.

To some people the communication of disease through an infected water or a water carrying pathogenic bacteria seems to be mysterious, and because it does not come in some tangible form, they are disposed to doubt the transmission of infectious disease by this means altogether, and of those who recognize danger in polluted water few are aware of the number of germs known to be pathogenic to man or animals which have been found in drinking waters, some of which were not suspected of being the carriers of infection.

In Eisenberg's * list of bacteria possessing pathogenic properties 12 kinds are described which have been found in water. Dr. Sternberg † gives a list of 16 pathogenic bacteria found in water; while Professor Frankland ‡ enumerates 23 species of such bacteria found in water. Of these the most formidable are the germs of cholera and typhoid fever, and as cholera rarely visits this country, typhoid is the principal pathogenic bacteria with which we have to deal.

The mass of evidence on the cause of typhoid fever abroad and in this country is to the effect that it is invariably a water-carried disease, and in those epidemics where milk, butter, etc., are the immediate distributors of the germ, water used in connection with the dairy or in culinary operations has been the original habitat of the typhoid bacillus, from which it follows that if the typhoid germ is kept out of our dietetic water supplies, typhoid fever would cease to exist.

The author expects this statement to be disputed by some investigators, but he is not aware of any proof that typhoid fever can have existence after our domestic waters have been rendered sterile, or are known not to furnish a home and means of transportation for the bacillus.

The germ comes into our drinking and domestic waters from a sewage source; the alvine discharges of one sick with typhoid fever are run into the sewers or deposited in a domestic privy vault or on the surface of the ground, and by subsoil and surface drainage, or by air currents, are carried into the rivers, lakes and ponds, upon which as communities we rely for our daily supply of water. From the water,

* Bacteriological Diagnosis. By Dr. James Eisenberg, Vienna,, 1887.

† Manual of Bacteriology. By Dr. George M. Sternberg, New York, 1892.

‡ Micro-Organisms in Water. By Percy and G. C. Frankland, Dundee, 1894.

the germ is taken into the human system again, and, if a nidus is found in the intestinal canal, the germ establishes itself, propagates by fission, elaborates its poison (*typho toxin*), and the ulceration of the Peyer's patches, and other symptoms of typhoid fever are established.

Thus the life history of the typhoid bacillus may be stated: *First*, as a residence during the early part of typhoid or typho-malarial fever in the human intestine; *second*, the transfer of the fæces containing the bacilli through the water-closet and sewer, or subsoil, or surface drainage, from the premises where typhoid is prevailing to the river or other point of discharge of the sewage or drainage; *third*, a residence in the water of the river, lake, pond or reservoir (as at Plymouth, Pa., 1885), and, *fourth*, finally back again into the human system through the drinking of the water containing the germ, or through the use of an article of diet which has been brought in contact with the typhoid-infected water.

The human intestine, the liver, spleen and mesentery gland is the normal habitat or residence of the typhoid fever germ (*typhi abdominalis*). Here it finds the surroundings most favorable to its development, and from the spleen or other organ of one dead of typhoid is obtained by inoculation of a gelatine tube the minute organism which is held to be the cause of this dreadful plague of modern times. The typhoid bacillus when taken from a gelatine culture is a straight rod with rounded ends, about $\frac{1}{15000}$ in. long, and generally one-third of this in width and thickness. If one can imagine a link sausage as small as this he will have a fair idea of the shape of the bacillus. It consists of the lowest kind of living matter, protoplasm within a cellulose envelope; it forms no spores nor seeds, and propagates by fission; that is, by the elongation of the cell or rod and a division in the middle into two cells or rods, each of which again divides into two rods, and so on indefinitely.

Thus one germ or one of these little rods, of which it takes 15 000 placed end to end to make 1 in., may, under favorable conditions, become the parent of millions within a few days or weeks. It is not a rapid-growing germ, like the germ of cholera, for instance, which will fully develop in 24 hours, but grows slowly, requiring in artificial media at room temperature from a few days to two weeks to attain its normal condition of growth.

It is not a hardy germ, excepting in its ability to resist a slight

acidity in its nourishing medium, but other germs are known to have a greater resistance to acid solutions than the typhoid germ. It is an exceedingly difficult germ to differentiate or demonstrate, because in microscopic appearance quite a number of harmless (or supposed at the present time to be harmless) bacilli resemble it so closely that the difference between the several kinds of germs when grown in the same solution is usually less than the differences between the typhoid germ itself at different times from different culture materials. In its growth on gelatine, agar and potato, the favorite materials for the cultivation of all but the nitrifying bacteria, it resembles several other bacteria so nearly that differentiation from its simple growth on these materials, even when taken in connection with its microscopic appearance, is quite impossible.

At this point it is well to note that notwithstanding the many earnest attempts to successfully demonstrate the typhoid bacillus in water, etc., considerable doubt surrounds the results of all such investigations at the present time, and methods which a short time ago were supposed to be infallible in the differentiation of the germ have been shown by later tests to be wholly unreliable. Thus, the growth on sterilized potato, which at one time was regarded as characteristic of the bacillus, is now known not to be uniformly consistent, and other germs give quite the same appearance as typhoid when grown on potato.* The number of cilia or flagella has been regarded in Germany as an important element in the differentiation of the typhoid bacillus, but the author has been unable to demonstrate the flagella from growths of an imported (Berlin) germ, and others in Cincinnati who have attempted to show the cilia have been rewarded with negative results. The English tests† and the tests of the Massachusetts State Board of Health, as these are understood by the author, do not involve the demonstration of the cilia on the bacillus as an element in the differentiation of the germ. The growths in an acid solution are open to grave objections, as shown by the extensive investigations of Dunbar‡ and others, and altogether the demonstration of the typhoid bacillus in water, etc., may be still regarded as surrounded by some doubt. The author's method is to carry forward at the same time under the

*Differentiation of the Typhoid Bacillus. Annual Report Massachusetts State Board of Health, 1891, p. 637. By Geo. W. Fuller.

† Micro-Organisms in Water. By Percy and G. C. Frankland, 1894, p. 267 *et seq.*

‡ Zeitschrift f. Hygiene. Vol XII, 1892, p. 485.

same conditions of media and temperature, growths of the bacillus taken from the spleen of a typhoid subject, and of the suspected germ found in water, and if the results of microscopic examination, appearance on gelatine and agar plates, and in gelatine and agar tubes, and in the acid reaction in sterilized milk are the same for both growths, then to turn the supposed typhoid growth over to a medical friend for observation of the symptoms from inoculation tests on the lower animals.

Several methods of differentiation are now known which, in skillful hands, will enable one to form a fair judgment on the presence of this germ in a suspected water or article of diet. But the decisive test is to be had only by many carefully conducted inoculations of the germ into the animal system.

This is the germ of Eberth, found in the spleen of a typhoid fever subject, and germs resembling this in all outward respects have frequently been found in drinking water, inoculations of which into dogs, cats, rabbits and guinea pigs have been followed in many cases by death within a day or two, after a series of symptoms resembling somewhat the typhoid symptoms in man. Inoculation tests, of course, have never been made upon man, and, until this has been done, the final proof of the etiological relation of this germ to typhoid fever will be wanting (Sternberg), but all the evidence of the past 13 years clearly demonstrates the Eberth bacillus as the cause of typhoid, and all the investigations of typhoid epidemics as clearly indicate an infected water (or milk or other article of diet infected from water) as the carrier of the germ or cause of the disease.

For drinking and other dietetic purposes every community, in fact every household, should have a sterile water. A sterile drinking water cannot be found in Nature (hot springs and geysers not being regarded as sources of drinking water), the use of which will avoid the introduction into the human system of the germs of disease, and especially of typhoid fever. Water that contains no pathogenic bacteria and which is above or beyond the influence of sewage pollution can be found, but, unfortunately, seldom where it can be made available for a city supply.

DISCUSSION.

Mr. Harris. ROBERT L. HARRIS, M. Am. Soc. C. E.—A series of experiments was made in Providence, R. I., in 1893 and 1894, lasting 12 to 15 months, and an exhaustive report on the results was made to the city. This report indicates that mechanical filters act on bacteria.

Mr. Hering. RUDOLPH HERING, M. Am. Soc. C. E.—It is stated that the Providence experiments to which Mr. Harris referred have revealed nothing new. It is claimed by several parties interested in artificial filtration that the flocculent mass caused by the addition of alum or other coagulents settles upon the surface of a water filter, and thus strains out the bacteria.

The new filters built for purifying the water supply at Lawrence, Mass., furnish a good illustration of their apparent ability to exclude typhoid bacilli. For many years the State Board of Health of Massachusetts has recorded the appearance of typhoid fever cases in Lowell and Lawrence, and has found that a few weeks after the fever appeared in Lowell, it also appeared in Lawrence. It is supposed to be caused by the water supply, because the Lawrence supply is taken from the Merrimack River, which receives the sewage of Lowell. Since the filters were introduced in the fall of 1893, there has been another similar epidemic in Lowell, and for the first time on record it was not followed by one in Lawrence among persons drinking the filtered water, showing that these filters, which were constructed with the greatest care to secure this result, very likely did accomplish it.

The author's assertion that typhoid fever can be propagated only through drinking water is certainly incorrect. In Europe, and particularly in Germany, there is a large class of eminent men who hold another view. Physicians are divided into two classes on this subject, one holding the ground-water theory, and the other the drinking-water theory. There are some interesting diagrams of observations in Munich and Hamburg showing the deaths by typhoid fever in relation to the level of the ground-water. The correspondence between the death rate and ground-water curves is remarkable. In Hamburg the water supply is taken from the Elbe River, a tidal steam, and has nothing to do with the ground-water level, yet, when the latter rose, the typhoid fever mortality was greater, and *vice versa*. There has been no satisfactory explanation of the reason of this. Most cases of typhoid fever are propagated by drinking water infected with typhoid bacilli, but there are other means of disseminating this disease.

Mr. Dunham. H. F. DUNHAM, M. Am. Soc. C. E.—It is generally understood in this country that the water in streams is less desirable for drinking when they are very low. If they are polluted to a certain extent throughout the year, in that season when there is the least water in

them, it is the least desirable for drinking. As the lowest level of the ground-water occurs when the flow of the streams is least, it may be that this fact is an explanation of the correspondence between the curves mentioned by Mr. Hering. Mr. Dunham.

Professor A. A. Breneman.—Perhaps the action of the coagulent in filtration may not be entirely understood by all; it is much like that of the white of an egg or isinglass in clearing coffee. It forms when diffused in the liquid an all-pervading web like a thin jelly, and being less movable than the liquid, it follows that whether it be allowed to settle or whether it be filtered out, it entangles the bacteria or their germs, and is a means of purification, an additional mode of action other than that of coating the surfaces of the filtering material with a viscous layer to which solid particles adhere during filtration. Mr. Breneman.

It has been suggested that the beneficent action of bacteria might not be generally appreciated. We are dying by the action of bacteria, and we are living by the aid of bacteria. It may be interesting to know that just as we have long been cultivating yeast plants and have brought beer and wine to the proper condition by this means and by excluding the wrong organisms, so at this time our butter and cheese are coming to be regulated by bacteria; the bacteria suitable for the proper production of butter and cheese have been sold commercially.

It seemed to the speaker that the pendulum is swinging too far in the direction of bacteriology. Bacteriology has not done much in showing the existence, in a given case, of a specific pathogenic bacillus in the water of a well or stream examined for domestic use. It has much to do in the testing of the efficiency of a filter by showing the relative abundance of bacteria or their germs before and after filtration. Bacteriological examination furnishes merely a presumption for or against the water, as chemical analysis does. The proportions of free or albuminoid ammonia, of nitrates or nitrites, which indicate the present or previous existence in a water of putrescible animal matter, have been shown by hundreds and thousands of water analyses on record to bear certain definite relations to the adaptability of the water for domestic use. It must not be forgotten, also, that the methods of chemical examination have their place and will always have their place; they are improving *pari passu* with the methods of bacteriology and must always be taken into account.

Charles E. Emery, M. Am. Soc. C. E.—All filters may be so constructed as to have a mechanical action; for instance, screens and filtering material may take out leaves and other large floating objects which can be seen, and some of the organisms may also be removed in this way; but the jelly which finally shows itself on the filtering material is a beneficent growth and the nidus of beneficent forms of life, no matter whether of an animal or vegetable nature, all Mr. Emery.

Mr. Emery. of which should be permitted and encouraged, as they absorb and destroy pathogenic germs which are the cause of disease.

It is interesting, and in the same line of thought and investigation, to notice that some of the new schools of medicine are using a form of life producing one disease to destroy the form which produces another. There has been a fair measure of success obtained in the cure of cancer by giving the patient erysipelas. Smallpox thrives as long as the pabulum exists which will support it. In due time the particular nutriment is exhausted by the continued reproduction of the organism and the disease dies. This particular pabulum can, however, be exhausted or modified by the much less dangerous kine-pox, and thereby immunity be obtained from smallpox. It is well known that some diseases of the blood have the effect of driving out all pre-existing forms of similar disease, which may be explained on the above principle, or features of animal life may be supposed to be reproduced in miniature and the existence of carniverous bacteria assumed. In fact, it is credibly reported that the phagocytes forming part of the white corpuscles of the blood have been seen through the microscope to issue upon the surfaces of the mucous membrane in the throat and actually absorb bacilli carried upon such membranes through the air. The different tissues of the body represent various forms of life, each independent, in a sense, according to a special law, and the function of the animal extracts now in vogue depends upon the principle of making these beneficent forms of life stronger, particularly the white corpuscles, thus enabling them to carry medicine and nutriment, and destroy the germs which cause disease. It is thus seen that in the preservation of the human system and in the preparation and care of food and water to sustain it, guidance is afforded by the same rules that form the basis of strength of the community. We must protect our friends and drive out our enemies. It has been found that poison placed in a filter, while destroying many pathogenic germs, also destroys the growth which is chiefly responsible for thorough purification. The study of a water supply involves the study of many kinds of life, and it is largely by the promotion of the beneficent forms that those which are injurious are eliminated.

CORRESPONDENCE.

Mr. Sherman.

CHARLES W. SHERMAN, Jun. Am. Soc. C. E.—Before the introduction of the Sedgwick-Rafter method of collecting the larger organisms of water for microscopical examination, the biologist of the Massachusetts Board of Health had a method of filtering out the organisms which seems much simpler than that used by the author. It consists in stretching a piece of cotton cloth tightly over the tap or the end of a funnel, and allowing the water to run through it for some time. The cloth is then removed, turned inside out, and stretched tightly over the end of a glass tube. By blowing smartly through the tube many of the organisms are detached, and they are then placed under the microscope for examination.

The author seems to imply that the bacilli of typhoid fever are likely to pass through sand filters owing to their small size, while the ordinary harmless water bacteria are retained. This would undoubtedly be the case if filtration were only a process of straining, but it has been abundantly proved that this is not the case. It has been shown at the Lawrence Experiment Station that *B. prodigiosus*, a harmless species, differing very little in size from *B. typhi abdominalis*, passes through the filters in a much smaller proportion than the ordinary water bacteria. On page 455 of the Report of the Massachusetts Board of Health for 1893 is a table from which it appears that the percentages of water bacteria remaining in the effluent varied between 1.04 and 2.34, while of the applied *B. prodigiosus* only from 0.15 to 0.46% appeared in the effluent.

Like the results of a chemical analysis of water, the figures of a quantitative bacteriological examination can be taken only as indications, never as absolute results; for not only do some bacteria develop much more rapidly than others—so much so, in fact, that a plate might be entirely liquefied by one species before the colonies of another would be visible—but it is a well-known fact that there are bacteria which do not develop at all on the ordinary culture media. One of these is the nitrifying organism, which is undoubtedly present in most natural waters, probably in considerable quantities, and does not grow on gelatine. A prolonged search has failed to bring to light any data relating to the proportion of the bacteria in a water which will develop on a gelatine culture; as a mere guess, perhaps from two-thirds to three-fourths may be assumed. Without in any way disparaging the author's experience with the Pasteur-Chamberland filter, the writer would say that a few samples he has planted from such a filter, one which does not receive extraordinary care, have proved sterile in every case.

Dr. Gehrmann.

Dr. ADOLPH GEHRMANN.*—The method of carrying out bacteriological analyses by the Department of Health of Chicago is as follows: The samples are collected from the pumping stations of the city in 1 gall. glass bottles closely stoppered, which are sterilized in a steam sterilizer. After the bottles are filled, they are brought immediately to the laboratory, the analysis thus being made within one hour. The portions of the samples that are added to nutrient media are removed with a small pipette from the bottle, after it has been well shaken. These pipettes are glass tubes, graduated in tenths of a cubic centimeter, and sterilized in large test tubes. The fluid in the pipette is dropped into the melted medium immediately after the pipette is filled, and plate cultures are then made. These are always made in series on gelatine and agar. The amounts of water placed in the plates are 0.1 cu. cm., 0.5 cu. cm., and sometimes 1 cu. cm., different pipettes being used in the counts. Upon the fifth day the colonies resulting are counted by using rulings upon slate placed under the Petri saucer, over which is placed a magnifying glass. If the colonies are numerous, the plate is averaged. Finally, the resulting counts of the different amounts of water are averaged, and this is taken as the number of bacteria in the sample. At the same time, 1 cu. cm. of the sample is added to bouillon containing 0.15% of carbolic acid, and the flasks are placed in the incubator for 24 to 48 hours. If clouding results, cultures from them are made again, and some of the bouillon is injected into guinea pigs and white rats, which is considered the best means for discovering pathogenic organisms.

The author's statement as to finding great variation in the numbers of the count is a fact frequently noticed in Chicago, and for this reason the cultures are made in series. The author's experiments with the dropping tube are very interesting and the Chicago Health Department will determine its further possibilities. There is no doubt but that the statement of results should be in round numbers; it is certain that the result is only relative, and that fractions do not count. As to the presence of pathogenic bacteria in the water, it is certainly one of the most difficult questions in the subject and one that even yet demands the closest study.

Mr. FitzGerald

DESMOND FITZGERALD, M. Am. Soc. C. E.—Any study that is given to the subject of organisms in water used as a source of domestic supply should receive encouragement. Many years ago the writer passed through several trying periods in connection with bad tastes developed in the water supplied to the city of Boston, which is derived from lakes and artificial storage basins. These troubles were clearly traced to the large amount of organic matter in the water giving rise to abnormal growths of algæ and other organisms, and it is now known definitely that the lack of proper preparation of the bottoms of the

* Superintendent of the laboratory of the Department of Health of Chicago.

reservoirs was largely instrumental in bringing about these growths. An enormous amount of money was expended in rectifying the evil, and believing that a more careful examination of the whole subject should be made in a scientific manner, a small laboratory was erected at Chestnut Hill Reservoir for the sole use of the Water Department of the city of Boston. This laboratory has now been in operation for about five years. Samples of water from all the reservoirs and sources of supply, taken from the surface, mid-depth and bottom, are sent weekly to the laboratory and duly classified, the organisms and amorphous matter counted by a speedy method and entered in books especially prepared for the purpose. The colors and temperatures of the waters are taken at the same time, and in conjunction with chemical analyses, enable a careful watch to be kept over all changes going on and facilitate studies of the causes producing them. Already valuable data have accumulated which are of practical importance in the management of the supply and which the writer hopes will be of value to others whenever they can be properly arranged and published. Mr. FitzGerald

In the Report of the Boston Water Board for 1894, an attempt has been made to show the causes of the sudden increase in the growth of organisms in the great periods of circulation in the spring and autumn due to the overturning of the waters and the distribution of food throughout the mass.

The following is a list of the predominating organisms in Lake Cochituate, Basins 2, 3 and 4, and Chestnut Hill Reservoir, and the number (in standard units*) which they are liable to reach without becoming abnormally large.

	Lake Cochituate.	Basin 2.	Basin 3.	Basin 4.	Chestnut Hill Reservoir.
	Per cubic centimeter.	Per cubic centimeter	Per cubic centimeter.	Per cubic centimeter.	Per cubic centimeter.
Asterionella	750	.....	400	.....	150
Melosira	500	.....	.....	.....	50
Tabellaria	800	50	800	.....	200
Synedra	250	300	250	.....	150
Stephanodiscus	200	.....	.....	.....	150
Protococcus	350	75	200	100	100
Cœlosphærium	100	.....	2 500	.....	50
Clathrocystis	150	.....	300	.....	50
Microcystis	250	.....	200	25	100
Anabæna	50	.....	200	.....	.....
Anabæna (sterile)	150	.....	.....	.....	50
Crenothrix	510	.....	.....	.....	.....
Synura	25	.....	50	.....	.....
Cyclotella	.....	50	150	50	50
Raphidium	.....	75	.....	50	.....
Chroöcoccus	.....	.....	150	.....	.....
Dinobryon	.....	.....	75	.....	.....
Trachelomonas	.....	.....	50	.....	.....

* The unit of measurement used by the Boston Water-Works for the organisms is 400 square microns.

Mr. FitzGerald The number of bacteria in the Boston water is now very low. In the distributing reservoirs it is generally 60 per cubic centimeter, and in the tap water 50 per cubic centimeter.

Mr. Riffle. A. S. RIFFLE, M. Am. Soc. C. E.—The subject of water and sewage purification is a vexed one. Just so long as the people passively recognize the prescriptive rights of riparian ownership by individuals, corporations and municipalities to discharge sewage and wastes into water-courses without previously removing those impurities which are the accepted causative agents of infectious diseases, just so long will water consumers be subjected to the visitation of typhoid, cholera and other zymotic diseases.

Although the purification of sewage in this country at present may be said to be in its experimental stage, yet the results thus far have been highly satisfactory, both as regards utility and cost of operation. The system of East Orange, N. J., a combination of chemical treatment and intermittent filtration, forcibly illustrates the possibilities of sewage purification, in that an analysis of the final effluent showed water much purer than that of the Passaic River, its secondary outlet, the entire cost of operation being about 60 cents per capita per annum. Many other systems of more or less magnitude, both separate and combined, show a cost of operation and maintenance varying from 6 cents to 50 cents per capita per annum.

This moderate cost of operation, together with the possibility of employing either irrigation, filtration, or chemical treatment, or a combination of these systems, certainly invites the careful consideration of those municipalities utilizing water-courses in thickly settled districts as a means of sewage disposal. However, conditions must be accepted as they are found, and the unwholesome quality of our river water is quite certain to exist until co-operative legislative enactment deprives property-owners of the right to convert public waterways into public sewers. This being the case, it perhaps comes more within the province of this discussion to refer to those precautionary methods which will insure the removal or destruction of micro-organic life to such an extent as to render potable the polluted waters which form supplies for so many of our cities. An appalling list of 300 000 or 400 000 cases of typhoid alone each year, with a mortality of fully 10% beside the mortality from various other zymotic diseases, all having their origin undoubtedly in the pathogenic micro-organic life in water supplies, certainly calls for the careful and exhaustive biological investigation of all sources suspected of contamination. The failure of so many municipalities, especially the smaller ones, to provide for a reliable chemical and bacteriological investigation, is due, not so much to excessive frugality, as to a non-realization of its importance. It seems to be human nature, despite facts, to regard clarified water as presenting unquestionable proof of purity while it may be foul with the germs of death and disease.

In the eastern and middle states, especially in the districts of dense population, the question of water pollution becomes one of greater importance than in the Pacific states, where, in a majority of cases, absolutely pure supplies may be obtained from uncontaminated mountain streams. These conditions are beginning to disappear, however, owing to the growth of villages and cities, and the western engineer will soon be confronted with the same problem that engages the attention and skill of the eastern expert. Mr. Riffle.

A municipality which is able to obtain an adequate supply of water from a district of uncontaminated drainage at a moderate cost is indeed fortunate. A combination of these conditions is exceedingly rare. The extreme cost of a system involving a long conduit compels a vast majority of our cities to use supplies found at their doors, regardless of the quality. It is for these less fortunate localities that the present paper has the greatest value. The use of an efficient filtration plant then becomes the only alternative. Although there is much dispute as to the efficiency of the most complete filter plants to arrest the passage of the minute pathogenic varieties of bacteria, yet their utility must be in a large measure accepted, inasmuch as a large decrease in the number of cases of zymotic diseases always follows their use. A comparison of statements as to the utility and cost of operation of the various large filtration plants in operation in this country would be of interest and value. Dr. Peter T. Austen is authority for the statement that at Atlanta, Ga., a battery of 12 filters delivers 4 000 000 galls. per day at a cost of $3 83 per 1 000 000 galls. Will the author of this paper state if he is familiar with the workings of the London filter plant, whether a coagulant is used in preparing water for filtration ?

Daniel W. Mead, M. Am. Soc. C. E.—An absolute criterion of the purity of water for domestic supplies is greatly to be desired. But unfortunately such has never been found, and from the nature of the case, never can be found. The possibility of such a criterion must depend both on the possibility of the establishment of the fact that certain data absolutely and completely demonstrate the quality of the water tested, and also that all the water, of which that tested is a sample, is essentially the same as the sample. Various data have been proposed at different times, and advocated as the desired criteria of purity, but each in turn has been abandoned or relegated to its proper position, as it has been found to be, at best, but an imperfect measure of quality. Various chemical products of organic decay have been proposed at different times, but none have been found to give more than a general knowledge of the purity of waters, and even this general knowledge depends for its value on a collateral knowledge of the history of the water so examined. The same general conditions must also hold with the biological examination of water. Such an examination will give evidence indicative of certain conditions, but it can never serve as an absolute criterion of purity. Mr. Mead.

Mr. Mead. It is well established that organic dissolution cannot occur except through the intervention of bacterial agencies. The bacteria are the cause of decay, and the results of such decay are manifest in certain chemical products. Chemistry and bacteriology therefore supplement each other in the determination of the class and nature of organic matter. A great variety of bacteria seems to exist in nature, each class having distinct functions. Thus it is the function of the yeast bacillus (*Saccharomyces cerevisiæ*) to cause the fermentation which results in decomposing the sugar in grape juice, or other solutions containing sugar, and converting it into alcohol and carbonic acid. Other bacteria of the same family possess similar functions, but they vary somewhat in the methods and the results of their action. Still other bacteria have entirely different functions, developing only in their proper mediums and under favorable conditions. The various saprophytic bacteria operate on different forms of organic matter and in different ways, one point being common to all, that in their development they cause the dissolution of the matter they attack and the rearrangement of its constituents in new forms. The pathogenic bacteria differ from the saprophytic only in the fact that they attack living animal tissues, and in their development they destroy or attempt to destroy these tissues, and in so doing produce the symptoms of the diseases which, when carried to certain lengths, produce death. The saprophytic bacteria are by far the most numerous, occurring in all the water we drink, the food we eat, and the air we breathe ; and they are particularly abundant wherever decaying organic matter is abundant. They are therefore found in abundance in sewage, in garbage, and in all animal filth ; and if such filth is so located that it may receive the dejecta of animals having diseases of bacterial origin, pathogenic bacteria may also be present.

From these considerations it is evident that as all normal waters must contain some organic matter, so the presence of bacterial life is also a normal condition. The increase in the number of bacteria is also a fair criterion of the increase in organic matter, but it is also clear that such organic matter may or may not be from a source productive of pathogenic bacteria, and hence may or may not be objectionable. A knowledge of the natural history of the water is therefore essential in order that the source of the bacterial life may be judged. It is, of course, possible by the identification of species to class sometimes the accompanying organic matter, but this cannot be done with sufficient exactness and facility at present except in extreme cases.

It is evident that the only absolute bacterial criterion of purity or pollution is the isolation of pathogenic bacteria from the water examined, and this is only for the individual portions examined. The life history of any bacillus may be concomitant with that of any drop of water in which it may chance to be, and its absence or presence in one

isolated portion is not conclusive evidence of the same fact relative to other portions. It is therefore believed that bacterial examinations cannot be relied on as giving conclusive evidence of the purity of any water supply, but should be regarded as one of the valuable aids toward determining such facts and conditions. Neither for the same reasons can a bacterial examination be regarded of itself a sufficient determination of the completeness of the various processes of clarification of a supply known to be more or less polluted. Such an examination may show improvement or deterioration in the quality, but nothing more, unless the bacteria are entirely absent. All criteria proposed, therefore, are of value in a relative sense only. They may be considered exact in the extreme cases of purity or pollution, when the surroundings are also demonstrative of the conditions there shown, but in the limiting case where a suspected water must be used if possible, no single criterion can ever give an absolute demonstration of freedom from dangerous organic pollution. Mr. Mead.

Allen Hazen, Esq.—The paper has brought out a number of interesting facts along a line which is not sufficiently understood, and in regard to which every communication must be received with interest, and can hardly fail to produce valuable results. There are, however, one or two points which have apparently escaped the author's attention, the knowledge of which will, perhaps, tend to a better understanding of some of the facts which he discusses. Mr. Hazen.

In the first place the numbers of bacteria in the London water before and after filtration do not represent the efficiency of filtration in removing bacteria, as is often, and quite naturally, supposed to be the case. It has been found repeatedly that with filters in the same, or nearly the same, condition, the numbers of bacteria in the effluents have often been nearly constant, notwithstanding very wide fluctuations in the numbers in the unfiltered water, and this fact has been so pronounced as to lead some investigators to maintain that the bacteria in the effluents do not come from the unfiltered water, but from independent sources in the under-drains or gravel of the filters. This extreme view, however, is not supported by the latest information from Berlin, Hamburg and Altona, where this question has been studied in great detail, nor by the exhaustive experiments which have been conducted at the Lawrence Experiment Station. These later results indicate that the bacteria in the effluent from the filter are ordinarily from each of two sources; a part of them come through the filters from the water filtered, and the numbers which pass in this way bear tolerably definite relations to many of the conditions of filtration, particularly to the rate and to the depth and quality of the sand, while the other bacteria have their origin in growths in the gravel or under-drains, where harmless species, which are capable of growing upon the extremely small quantities of organic matter there present, establish themselves upon

Mr. Hazen. the stones or walls of the drains and multiply and are washed off from time to time by the current of the passing water, and join those which have actually passed through the filter.

A full discussion of the causes which control the numbers of bacteria from these two entirely distinct sources would occupy too much space. Attention is called to the fact that the numbers of bacteria in the effluents from the London filters are very much greater than the numbers which there is reason to believe have actually passed through the filters, and as it is this latter number alone which is dangerous to health, the percentage of removal of bacteria, as calculated by the author, is not so great as the actual efficiency of the filters, unless it is shown that the bacteria of typhoid fever pass through filters much more freely than the kinds of bacteria in river waters. The author alleges that this is the case, citing the death rate of London as evidence, and explains the fact by the statement that the germs of typhoid fever are smaller than other species. As a matter of fact, the typhoid bacteria are not particularly small when compared with the bacteria most common in waters. Further, the passage of the typhoid germs has been experimentally investigated at the Lawrence Experiment Station of the Massachusetts State Board of Health, and it has been found that instead of their being able to pass more freely than other species, exactly the reverse is the case, and the proportion of the typhoid germs appearing in the effluents is in general much smaller than the proportion of all the bacteria.

It is also assumed by the author that all the typhoid fever in London is due to the water supply, and, in doing so, he has overlooked the fact that polluted water is by no means the only carrier of the germs. Professor Sedgwick has shown admirably in the Report of the Massachusetts State Board of Health for 1892 that this is by no means the case, but that infected milk is also an important carrier of this disease, and that the fever is carried from one person to another by direct personal contact much more frequently than is often supposed.

As a matter of fact, the death rate from typhoid fever which a city is capable of attaining with a perfectly pure water supply is not *nil*, but instead is largely dependent upon the amount of typhoid fever in the surrounding country. In parts of Germany, where the water supplies are controlled by Government and are uniformly of excellent character, the death rate from typhoid fever has gradually declined to almost nothing, while a city surrounded by districts where the disease is prevalent will have a considerable number of cases which are brought in from the surrounding country by infected milk and other means however pure the water supply of the city may be, and this will prevent its attaining so low a death rate as would otherwise be expected. This is particularly true in English and American communities on account of the large amount of travel from city to city.

Mr. Hazen. The death rate from typhoid fever in London is considerably lower than the average for England and Wales, and there is every reason to believe that most, if not all, of the fever in London is from other sources than the filtered river-water supplies. A part of London is supplied exclusively with water from deep wells in chalk, furnishing a water which there is every reason to believe is absolutely free from infectious matter. The portion of London supplied with this water had a death rate from typhoid fever of 123 per 1 000 000 for the years 1885 to 1891, and all of this fever is supposed to be due to other causes than the water. That portion of London supplied exclusively with filtered Thames water for the same years had 125 deaths from typhoid fever per 1 000 000, or almost exactly the same as in the population supplied from the wells in chalk, which indicates strongly that the filtered Thames water was no more injurious to health than was the well water. Other parts of London are supplied with filtered water from the River Lea, or with water from two of the sources at once, and had death rates ranging from 133 to 167 per 1 000 000, but it was thought that this slight difference could be accounted for by other causes than the water supply. The Royal Commission which was appointed to inquire into the character of the water supply of London, and made exhaustive examinations in the years 1892 and 1893, was totally unable to find evidence that the London water was injurious to health, notwithstanding the alleged fact that this Commission was appointed to secure evidence that the water was unwholesome, and that a new supply from Wales should be introduced.

No large American city has a death rate from typhoid fever as low as that of London, but some of them, New York, Brooklyn, Detroit and others, have death rates very much lower than other cities correspondingly situated but with inferior water supplies, and it may be seriously questioned whether the death rates in those cities are not as low as it is possible for them to be with the amount of infection which is constantly being brought into them from neighboring cities where typhoid fever is more prevalent. But other cities have typhoid death rates which are not only above the average, but are higher than those of all the cities in their immediate neighborhood, and such rates, taken in connection with the known pollution of the water supplies, afford ample evidence of the damage which is caused by impure water, although they do not measure it, for in any such case large numbers of cases of fever contracted by the use of the polluted water result fatally after the persons have moved or traveled to other localities where their deaths may be apparent evidence of the pollution of other water supplies which may be in reality wholesome.

Mr. Fuller. George W. Fuller, Esq.*—In looking over the paper it appears that the author is earnestly engaged in studying the problem of supply-

*Biologist in charge of the Lawrence Experiment Station of the Massachusetts State Board of Health.

Mr. Fuller. ing communities with pure drinking water. Notwithstanding these commendable efforts on his part, the paper contains several conclusions which will be questioned by sound sanitarians. In the first place, the author does not understand clearly how it can be that in London the death rate from typhoid fever has been reduced 85 or 86%, while the process of filtration removes 96 to 99.9% of the number of bacteria in the river water. As an explanation of this discrepancy, he offers the suggestion, that "while the general reduction of bacteria in the water has been 96 to nearly 100%, the reduction of the typhoid bacillus probably has been much less than this." The facts are that the removal of typhoid bacilli by filtration under normal conditions not only equals, but exceeds, the general bacterial reduction, as indicated by the percentage of removal of the number of bacteria in the unfiltered water. This statement is proved by evidence obtained in both Europe and America. The investigations at the Lawrence Experiment Station for the past four years, as detailed in the reports of the State Board of Health of Massachusetts, show clearly that it is less difficult to remove typhoid bacilli from water by filtration than those species for which water is the natural habitat. The chief reason of this, as indicated by numerous experiments, is that the typhoid germ does not grow in ordinary water or in water filters, while quite a number of the water species of bacteria multiply within the filter and appear in the filtered water.* Farther on in the paper may be found a possible explanation of the author's remarkable position with regard to the removal of typhoid bacilli by filtration. He states that typhoid fever is invariably a water-carried disease, and if the typhoid germ is kept out of dietetic water supplies typhoid fever would cease to exist. Everyone knows that pure drinking water is an extremely important factor in the reduction of typhoid fever, but the sweeping statement above cited is incorrect. Instances abound where communities are supplied with thoroughly safe public supplies of drinking water and where the death rate from typhoid fever is very low, but yet the disease is by no means eradicated. The facts are that good living and safe living require something more than pure drinking water; among other things, good drainage and sewerage, good plumbing, well-prepared food of good quality, and a close observance of the laws of personal hygiene are necessary.

In the Report of the Massachusetts State Board of Health for 1892 it will be noticed that in the report of Professor Sedgwick upon eight typhoid epidemics, four of them, representing 46% of the total number of cases, could not be associated in any way with the quality of the drinking water. These conditions are believed to be somewhat unusual, but are mentioned to show that typhoid fever may follow infected milk and personal uncleanliness as well as polluted water. In the Report of the Royal Commission on the Metropolitan Water Supply, page 67, it is stated that "every medical witness that has appeared

* See the Report of the Massachusetts State Board of Health, 1892, p. 527.

before us, whether his general feeling was favorable or unfavorable to the (London filtered) water, has told us unhesitatingly that he knows of no single instance in which the consumption of this water has caused disease." Professor Koch, one of the foremost exponents of the theory of the transmission of disease by drinking water, devotes the first page of his latest communication on cholera to refuting the statement that he is a drinking-water fanatic, or believes water to be the exclusive bearer of the disease germ. Without the presentation of further evidence, it is obvious that the author has gone too far in his zeal in the study of water supplies, and has reached a position which cannot be supported by facts. Mr. Fuller.

The writer is heartily in favor of providing communities with pure drinking water by practicable means, and realizes fully that the use of pure water, free from typhoid germs, would place the typhoid rate of many American cities far below the present rates. Nevertheless there is abundant proof to show that something beside pure water is necessary in order to extinguish this disease absolutely.

George W. Rafter, M. Am. Soc. C. E.—It is unfortunate that the author's determination of the organisms other than bacteria, present in the Ohio River, was not made quantitative as well as qualitative, especially since the Sedgwick-Rafter method of microscopical enumeration, as now used in the principal laboratories, renders it possible to make such determinations with very little labor. Moreover, the microscopical examination may assist in deciding how rapidly self-purification processes are operating. At the present time a mere list of the microscopical organisms is not considered of any special value, and it is to be hoped that if the author continues the interesting studies on which he is now engaged, he will remedy this defect in his future work. Mr. Rafter.

While the writer agrees with the final conclusion of the author, that only a water free from the influence of sewage contamination should be used for drinking, he is of the opinion that in cases where uncontaminated sources are out of reach, for financial and other reasons, filtration, if properly designed and efficiently operated, may be relied upon to remedy the evil. In towns where the water supply is wholly bad and the indifference or neglect of the municipal authorities leads to the ignoring of the whole question, individual citizens may still find relief by the use of properly designed, intermittently operated sand filters, which can be so arranged as to furnish an effluent free from the germs of infectious disease.

The author states that the normal habitat of the typhoid bacillus is in the intestine, liver, spleen and mesenteric gland of the human subject. This view at any rate is open to question, and a more probable one is that the typhoid bacillus is a saprophyte, capable of independent existence indefinitely outside the human body, with its normal habitat in the ground, the same as is the case with tetanus and anthrax.

Mr. Rafter. Final proof of the truth of this view is lacking, but so is proof of the correctness of the view taken by the author. All that can be done at present is to balance the probabilities as to which is the more rational. The author's view involves difficulty whenever it is necessary to explain the appearance of typhoid in localities previously free from it, and to which no typhoid patient has been imported. On the other hand, if the saprophytic character of typhoid is assumed, the difficulty vanishes and the explanation becomes easy. Travelers in regions remote from human habitations are sometimes attacked with typhoid, and while animals may have acted as the carriers of infection, this assumption also involves difficulties of no mean order.

Assuming, then, for the sake of the present argument, the correctness of the saprophytic view of the habit of the typhoid, it follows at once that the lack of relation between the results of filtration in London in the matter of the reduction of the number of bacteria and the reduction of the typhoid rate may not be due in any special degree to the imperfect action of the filters. In the vast city of London several hundred thousand people pass in and out every day, and when it is considered that under the saprophytic theory typhoid may grow at any place where there is organic filth to nourish it, and in view of the chances of infection which, therefore, arise from causes existing outside of the London water supply proper, but to which the users of that water supply are still more or less subject, the wonder really is, not that the reduction under the influence of efficient filtration is so little, but that it is so great.

The author is further disposed to assume that the typhoid bacillus passes through the filters in much larger number than the ordinary bacteria. On this point it appears that the experiments at Lawrence are decisive, especially those in which the typhoid bacilli to the number of several thousand per cubic centimeter were applied to filters with the result of either complete or nearly complete removal. As further showing the palpable incorrectness of the author's view that a smaller proportion of typhoid bacilli are removed than of the ordinary water bacteria, it is cited that, so far as known, the typhoid bacilli are very sparingly distributed in water, 25 per cu. cm. would be a very large proportion, much larger, it is believed, than has ever been found in any natural water. The author's view leads to the conclusion that the typhoid bacilli may pass through the best modern filters almost without any destructive action. But the contrary of this is shown by the experiments at Lawrence already referred to. It must be concluded, then, that the assumption of lack of efficiency of the London filters because of the smaller percentage of reduction in the typhoid death rate than of bacteria removal is possibly not founded on fact.

Mr. Hill. John W. Hill, M. Am. Soc. C. E.—The most important question raised in discussion of the paper is upon the accuracy of the author's

statement, "if the typhoid germ is kept out of our dietetic water sup- Mr. Hill.
plies, typhoid fever would cease to exist." In speaking of a dietetic water supply this is held by the author to include cooking water and water for washing uncooked articles of diet, as well as drinking water. In support of the view expressed in the paper, the author takes this opportunity to quote from three distinguished and reliable American authorities upon this subject:

"Out of every 100 cases of typhoid fever 99 come from infected drinking water."—(Dr. Cyrus Edson, Commissioner of Health, New York, in the New York *Tribune*, December 10th, 1894.)

"The diseases in which the death rate of Lawrence, Mass., especially exceeds that of other cities are typhoid fever and diarrhœal diseases, both of which are regarded as especially dependent upon the water used for drinking."—("Typhoid Fever in its Relation to Water Supply," by Mr. Hiram F. Mills, 1891.)

"In parts of Germany where the water supplies are controlled by Government, and are uniformly of excellent character, the death rate from typhoid fever has gradually declined to almost nothing."—(Mr. Allen Hazen, late chemist to the Massachusetts State Board of Health, in his discussion of this paper.)

Abundant testimony can be offered in support of the author's view, but it seems to be so generally accepted by "sound sanitarians" that it is not deemed advisable to consume space in further quotations from standard authority.

Common belief upon any abstruse subject is not always founded upon fact. But of those who have given the cause of typhoid fever most attention, substantially all are agreed upon an infected water as being the most probable cause of the continuous case and death rate from this disease. Mr. Hazen, in his discussion of the paper, has advanced a new cause or method of transmission of typhoid which, to the author, at least, is a revelation, viz., that the disease may be transmitted by personal contact, thus placing it among the contagious diseases. All medical and hygienic authorities which the author has had the opportunity of consulting upon the subject of typhoid fever universally negative the idea of personal transmission. The fact of several typhoid cases at about the same time in the same household can usually be accounted for without assuming personal transmission, and such experimental evidence as the author is familiar with upon the propagation of the disease is wholly at variance with Mr. Hazen's proposition.

In regard to the transmission of typhoid by milk, oysters, watercress and other vegetables, eaten uncooked, in nearly all such cases which have been fully investigated, the disease has been traced to an infected water with which such articles have come into contact. Absolute proof of this is not forthcoming in all cases, but the inference is fair from present knowledge that in probably no other manner can these articles of diet be infected. If the typhoid bacillus is in the air, even of hospital wards where the fever is prevailing, diligent search has

Mr. Hill. failed to reveal it. If the typhoid bacillus, or any other organism having the properties of the typhoid bacillus, is in the soil, the author is still to learn of it, excepting as conjectured by Mr. Rafter in his discussion of this paper.

If there be other causes than a typhoid infected water operating to produce the continuous case and death rate from typhoid fever, what are these causes? Has the Massachusetts State Board of Health, the foremost body of its kind in this country, demonstrated any other certain and continuous cause for typhoid fever?

These other causes, if there be any, should operate with the same force in London as in Lawrence, Mass.; yet it appears from the vital statistics of the two cities that this is not the case. London, with its large and heterogeneous population, should exhibit in greater degree than Lawrence the effects of typhoid infection from milk, personal uncleanliness and other causes mentioned, and yet it does not. Why should the death rate from typhoid fever at Lawrence, after the pure water was introduced, be from 15 to 24 times that of The Hague, or is it to be understood that the other causes of typhoid are more plentiful and active at Lawrence than at The Hague. Mr. Fuller offers no proof that personal cleanliness has any influence whatever on the transmission of typhoid fever; neither does Mr. Hazen submit any evidence in behalf of the personal contact theory, in the absence of which these new methods of transmission must be regarded as mere conjectures. A cause for the prevailing typhoid case and death rates must be explained from facts and not from the assumed facts which some one may think will be discovered a year or two hence, and by this standard the conclusion that an infected drinking water or water used in connection with some article of diet is the only probable cause cannot be avoided.

Mr. Hazen calls attention to some investigations of typhoid fever epidemics in Massachusetts during 1891 which were traced to infected milk, but he overlooks the conclusion arrived at by Professor Sedgwick in one or more of these, that the original source of infection was probably in a typhoid-tainted water used in the operations of the dairy. The same conclusion was reached in the investigation of the Montclair, N. J., typhoid epidemic, April, 1894.

In regard to the removal of the typhoid bacillus from water, the author has believed heretofore that this would be attended with the complete elimination of all typhoid fever so far as the local water supply is concerned, but the experience of Lawrence, Mass., since 1893 is calculated to shatter this belief. During this interval of time, the city has been supplied only with water from the new intermittent sand filter, based on the elaborate and exhaustive experiments on sand filtration at the Lawrence Experiment Station, and notwithstanding the fact that the water from this filter, according to report, is superior to

that of many of the larger cities of the world, and goes forth to the people with the seal of approval of the State Board of Health, many people will not drink it, preferring the canal water of known sewage pollution, and of those who do drink it some die of typhoid fever. Or to be exact, after the Lawrence water has been put through this filter, and allowing for the deaths from typhoid of those known or supposed to have drunk the sewage-polluted canal water, the typhoid death rate of the city is still so large when compared with other cities of this country and Europe as to leave room for suspicion that, after all, it may be a mistake to render water so pure. Taking the Lawrence typhoid death rate for 1894 as 48 per 100 000 of population living, including deaths of those who drank the canal water; and 30 per 100 000 of population living for those victims who drank no canal water, it appears that even after allowing that nine of the 24 deaths for that year were properly chargeable to the canal water, the remainder produced a death rate twice that of Newark, N. J., and greater than that of many other cities not claiming extraordinary purity for their public water supplies. Mr. Hill.

This state of fact raises an inquiry whether the bacillus of Eberth is really the true germ of typhoid, or, admitting, as the Massachusetts State Board of Health insists, that it is, then it is necessary to look to some other cause or causes for the 34% of typhoid fever still prevailing in that city, for be it known that the bacillus itself (as claimed) is removed from the water by filtration.*

Possibly the following information furnished the author by a professional acquaintance in Boston, himself an expert chemist and water analyst, and very deeply interested in the problem of sand filtration, may throw some light on the continued comparatively high typhoid fever death rate of Lawrence, Mass. Writing under date of May 25th, he says:

"In regard to the Lawrence filter would say that while it was designed to act intermittently, I have had Prof. C—— make a number of visits to the plant and at each visit he has learned * * * that the (sand) bed had not been exposed to the air for a great many days, and * * * that there was just as much typhoid fever among the users of the filtered water as among the users of the canal water."

In regard to the claim for the Lawrence filter of the complete removal of the typhoid bacillus from water, it will be more correct to state that it was not found in the effluent. The difficulty of determining the presence of this bacillus in any water is well known to workers in this line, and it is not always safe to assume that the bacillus is not in a certain water because one does not happen to find it. The author has made many tests for the bacillus in the Ohio River water, using all the methods of which he is aware, in addition to a method of his own for the separation of the typhoid from other germs in water, but without success so far. And yet in the light of the high typhoid fever rate

* See the Report of Massachusetts State Board of Health, 1892, p. 531.

Mr. Hill. of Cincinnati, even the exponents of milk infection and personal contact and personal uncleanliness modes of transmission cannot doubt the presence of the bacillus probably at all seasons of the year in the Ohio River water. Because a thing cannot be found is not evidence of its non-existence, and in the light of the continued typhoid fever rate of Lawrence, the author feels that there is a mistake in assuming the complete removal of the typhoid bacillus from the Merrimack water by the Lawrence filter.

In regard to the statement by Mr. Rafter that the typhoid bacillus may find a habitat in the soil, this may be true (for a time) of a soil polluted with sewage carrying typhoid dejecta; and in such instances any bacteria in the sewage may be found in the soil. The Eberth bacillus can be found more readily and more certainly in the spleen of a victim dying early of the disease than in the ground, and the standard cultures of the germ which investigators use are always taken from this source.

In a soil where active nitrification is in progress the typhoid bacillus could not live for any length of time. Its action on inorganic matter is antagonistic to the nitrifying organisms, and as these are supposed to prevail in all soils supporting growing vegetation, it is difficult to see how the soil can be regarded as the source from which the bacillus is obtained, at least in cases of infection. Granting, however, that it may flourish in such a soil, the chance of taking it into the system from this source is very remote when compared with the possibility of infection from a sewage-polluted water. The normal habitat of the bacillus would naturally be that place where it is most frequently and surely found, and where it develops its highest properties. So far as is now known this is the human system, and the spleen is the organism from which it is obtained for culture purposes.

In speaking of the possibility of the typhoid bacillus passing through certain so-called "germ proof" and sand filters, the size of the germ was compared with such bacteria as the author has been able to find in the Ohio River and other local waters. Of over 20 species thus far differentiated only two are in any dimension smaller than *B. typhosus*, viz., *B. fluorescens liquefaciens*, and *B. violaceus*. Since the paper was written some experiments with the bacillus taken originally from a spleen and inoculated into sterilized Ohio River water indicate that it attains larger proportions and agrees more closely with the typical germ as described by the German investigators than when grown in the customary solutions. Never having found it in the raw water of the river it is not known whether it grows as large in unsterilized as in sterilized water where there are no other organisms to appropriate the food substance.

Under this head it may be of interest to note that the bacillus lives with full power to promptly reproduce its kind in the sterilized Ohio

Mr. Hill.

River water for more than 60 days, the exact time at which the water culture lost its power of reproduction not being noted, but further experiments will be made to determine this time. It may also be of interest to note that in carrying forward parallel cultures of *B. coli communis* (culture obtained from Berlin) and *B. typhosus* (two cultures from different spleens), the interesting fact was developed in transferring *B. coli communis* from an agar culture to potato, that the bacillus obtained a size as large as *B. subtilis*, and upon retransferring from potato to agar it regained its normal size. Several tests were made to confirm this, with the unfailing result that the bacillus obtained the large dimensions when inoculated from agar to potato.

In regard to the capacity of the Pasteur filter to restrain the passage of water bacteria, the author desires to supplement the data in the paper with the results from some recent tests.

Pasteur filter furnishing prescription water in drug store, Cincinnati, O.

	Plates inoculated.	Counted.	Bacteria per cubic centimeter.
No. 1.....	May 16th	May 23d	201
No. 2.....	May 16th	May 23d	287
No. 3.....	May 16th	May 23d	236

Pasteur filter in popular restaurant, Cincinnati, O.

	Plates inoculated.	Counted.	Bacteria per cubic centimeter.
No. 1.....	May 16th	May 23d	182
No. 2.....	May 16th	May 23d	167
No. 3.....	May 16th	May 23d	293

Bowden double-chamber filter in a popular restaurant, Cincinnati, O. This is a sand filter using alum as a coagulant.

	Plates inoculated.	Counted.	Bacteria per cubic centimeter.
No. 1.....	May 17th	May 21st	153
No. 2.....	May 17th	May 21st	180
No. 3.....	May 17th	May 21st	176

On these last plates many liquefying colonies appeared which compelled an early count to avoid a total loss of the test. Doubtless some slow-growing non-liquefying colonies had not grown in the four days of incubation at room temperature. It is proper to note that all these plates were made with slightly acid gelatine, which is known to be inimical to the growth of some species of water bacteria.

Referring to Mr. Riffle's statement of the number of cases of typhoid fever in this country, from such statistics as the author has been able to collect, the present annual death rate from typhoid and typho-malarial fevers, typhoid pneumonia, and complications involving typhoid symptoms, is upwards of 50 000; and the mortality seems

Mr. Hill. to average from 13 to 14% of the cases. On page 156, Vol. XXXII of the *Transactions* of the Society, the author shows the mortality from epidemics of typhoid fever in the cities of Lowell, Lawrence, and Springfield, Mass.; St. Louis, Mo., and Pittsburgh, Pa., to range from 4.2 to 52% of the cases reported. From the typhoid fever records of the Cincinnati Hospital for the past four years the mortality was 18.30, 12.00, 3.70, and 14.75% of the total cases admitted for the respective years (1891–94 inclusive).

In reply to Mr. Riffle's question the author has not noticed any reference to the use of a coagulent with the London filter-beds and understands that none is used.

It is held by many experienced investigators that the typhoid fever death rate of any city is the best test of the quality of the water supply of such city, and as interesting data in connection with this paper the following typhoid fever statistics are quoted from another article by the author. The statistics were collated for comparison with those of Lawrence, Mass., since the new filter was put in service:

DEATHS FROM TYPHOID FEVER PER 100 000 OF POPULATION LIVING.
CITIES SHOWING A LOWER DEATH RATE THAN LAWRENCE, MASS.

In America, 1894: New York, 17; Brooklyn, 15; Newark, N. J., 15; Detroit, 26; Cleveland, 27; Boston, 28; Dayton, O., 20; Milwaukee, 26; New Orleans, 28; Toronto, 17. In Europe, 1893: London, 16; Manchester, 25; Edinburgh, 14; Glasgow, 20; Paris, 25; Amsterdam, 16; Rotterdam, 5; The Hague, 2; Copenhagen, 9; Stockholm, 8; Christiania, 6; Berlin, 9; Hamburg, 18; Dresden, 4½; Breslau, 10; Munich, 15; Trieste, 17; Vienna, 7; Budapest, 15; Brussels, 27; Venice, 26.

CITIES SHOWING ABOUT THE SAME DEATH RATE AS LAWRENCE, MASS.

In America, 1894: Lawrence, 30; St. Louis, 31; Philadelphia, 32; Chicago, 31. In Europe, 1893: Rome, 34; Turin, 29.

CITIES SHOWING A HIGHER DEATH RATE THAN LAWRENCE, MASS.

In America, 1894: Baltimore, 48; Washington, D. C., 71; Pittsburg, 56; Buffalo, 36; San Francisco, 35; Cincinnati, 50; Louisville, 72; Providence, 47; Jersey City, 76; Lowell, 55. In Europe, 1893: Liverpool, 53; Dublin, 87; St. Petersburg, 51; Moscow, 40; Prague, 36; Milan, 62.

The author does not suppose that the proper purification of the water supply of any particular city will have an influence upon the typhoid rate at any great distance from the city, but it will eliminate typhoid so far as the water supply of that community is concerned, and without question, any measures looking to the extermination of typhoid fever must be applied to every community and be available in every household to be effective.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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ADDRESS AT THE ANNUAL CONVENTION AT THE HOTEL PEMBERTON, HULL, MASS., JUNE 19TH, 1895.

By GEORGE S. MORISON, President Am. Soc. C. E.

The Constitution provides that the President shall deliver an address at the Annual Convention. It has been the custom to make this address a review of engineering works. I have thought right to depart from this custom. The year has been one of unusual dearth in engineering construction. I feel that it is the time to call attention to the true meaning and position of the profession and the society to which we belong.

Students of primitive society have divided the early development of the human race into ethnical epochs, representing various conditions of savagery and barbarism, and finally culminating in civilization; they recognize three periods of savagery, followed by three periods of barbarism. In the lowest epoch men were little superior to the animals by which they were surrounded. With the use of fire the

second period began. With the invention of the bow and arrow, the most primitive form of projectile, man entered the third period. With pottery, and all that it implies, he passed from savagery to barbarism. The next advance came with the domestication of animals, which gave man another power besides his own physical strength. With the manufacture of iron the last of the barbarous periods was entered. By the invention of the written alphabet the primitive race was promoted from barbarism to civilization.

To us the first, fourth and sixth advances mean more than the others. The use of fire first placed man in a condition very different from that of other animals, giving him a power the uses of which are even yet not fully developed. The domestication of animals was hardly less important, and although where animals suitable for domestication did not exist, tribes were able to pass this period without them, their weakness was apparent when they came in contact with other races whose conditions were not so limited. Finally the invention of a written language made the work of one generation available for its successors and produced historical civilization.

The changes which mark the advances from period to period are all material improvements; in every instance they are characterized by some distinctive physical device which has enabled man either to utilize his own strength better than before, or to increase his power by adding other animate or inanimate force. The race that passed from one period to another acquired resources which it had not had; in the contests which characterized the life of the primitive man, the men of a lower period fell before those who had risen higher. But though the devices were of a purely material character they gave opportunities for mental and moral improvement which alone made further advance possible, till finally the written alphabet culminated in that preservation of knowledge which has made the intellectual efforts of thirty centuries available for ourselves. With the dawn of civilization the ethnical periods have been considered closed; subsequent growth has been the natural advance of civilization marked by the events which make written history.

But there is no reason why the epoch which began with writing should be the last. It only needs a new capacity, radically unlike those which have gone before, to make an epoch in civilization as distinct as those in primitive society. Such new capacity has now been

found; another epoch has begun. Fire, animal strength and written language have in turn advanced men and nations, but the capacity of man has always been limited to his own individual strength and that of the men and animals which he would control. His capacity is no longer so limited; man has now learned to *manufacture power*, and with the manufacture of power a new epoch began. I use the words advisedly; creation, whether of substance or force, is not given to man; manufacture is not creation, but to change inert matter from one form to another in such way as to generate power is to manufacture power.

Furthermore, not only does the manufacture of power mark a new epoch in development, but the change is greater than any which preceded it; greater in its influence on the world; greater in the results which are to come.

The manufacture of power means that wherever needed we can now produce practically unlimited power; whatever the measure of a single machine, that machine can be used to make a greater one; we are no longer limited by animal units, confined by locations of water-falls, nor angered by the uncertain power of wind. Power can be had where it is needed and when it is needed. The manufacture of power has enabled us to concentrate in the hull of a single ship twice as much force as is developed by the whole water power of the Merrimac at Lowell, and this is but a trifle of what may be done.

The new epoch differs from all preceding epochs, in that while they represented successive periods of progress, different races have existed simultaneously in every period of advancement, whereas the new epoch must from its very nature soon become universal. The manufacture of power has given us the means of traversing the entire globe with a regularity and speed which brings all races together, and which must in time remove all differences in capacity. It brings people of all races into contact and by extending knowledge, ends the superstitions and mysteries which have had such influence in the past. It enables man while working in unhealthy districts to spend a portion of his time in places favorable to physical health and bodily vigor and so may end the climatic degeneration of race, which has done so much in history. It is gradually breaking down national divisions, substituting the natural boundaries of convenient government for boundaries based on race and ignorance. It will finally make the human race a single

great whole working intelligently in ways and for ends which we cannot yet understand.

It is not too much to predict that when the full effects of the manufacture of power are realized and the world has passed through the development which the next 10 centuries will see, that the time when man began to manufacture power will be recognized as the division between the ancient and the modern, between ignorance and intelligence, between the national strife which may then be classed as barbarism, and the new civilization, whatever that may then be called.

Great as the new epoch is, it means more to our own profession than to any other. The manufacture of power is the work of the engineer, the inventions which have led to it were made by engineers, in fact it has made possible the profession of the civil engineer.

The new epoch has barely begun. No exact dates can be fixed. Epoch making is not a matter of a single invention; it is the general result which follows. It was not the manufacture of the first earthen pot, but the general introduction of pottery which carried a prehistoric race from savagery to barbarism. It was not the invention of a few letters, but the general use of a written language which took the barbarian into civilization. It was not the invention of the first steam engine, but the general control of the manufacture of power which is now taking mankind into the new civilization. James Watt developed his first steam engine in 1769. The steam engine began to come into general use about the beginning of this century. The 19th century has seen the development of the manufacture of power by steam. The steam engine is still almost the sole representative of manufactured power, but there is no reason why this should continue. Electricity as a conveyer of power has been developed to an extent which may almost be classed with manufactured power. New forms of manufactured power may come at any time, but the introduction of new forms is a comparatively unimportant thing. The great advance came with the ability to manufacture power at all—the method is a secondary thing.

Here, then, we stand at the dawn of a great epoch, of an epoch making greater changes than the world has ever seen; we stand here as members of the profession which is most closely identified with this change and which has most to expect from it. Let us study the lessons which can guide us, in the duties and the responsibilities which are before us.

Let us consider what civil engineering is. The definition, incorporated in the charter of the Institution of Civil Engineers, is familiar to all : "The art of directing the great sources of power in Nature for the use and convenience of man." The Constitution of the American Society of Civil Engineers fixes as a requirement for full membership "the ability to design as well as direct engineering works." The English definition and the American requirement taken together explain what constitutes a civil engineer. His business is to design the works by which the great sources of power in Nature are directed. His works are not built for themselves nor as commemorative monuments ; they are made to direct the powers of Nature for the use of man. Every engineering work is built for a special ulterior end ; it is a tool to accomplish some specific purpose. Engine is but another name for tool ; the business of an engineer relates to tools ; a civil engineer must be capable of designing as well as handling tools. The highest development of a tool is an engine which manufactures power. All the great possibilities of our profession come from the existence of such tools.

It is a common error to think of civil engineering as a co-ordinate branch of a general profession with many other branches ; to class it with mechanical engineering, with hydraulic engineering, with sanitary engineering, with mining engineering, with electrical engineering, or with any other specific branch. The name of every special branch of engineering has a distinctive meaning ; the mechanical engineer deals with machines ; the hydraulic engineer, with water ; the mining engineer, with mines ; the sanitary engineer, with drainage, and the railroad engineer, with railroads. The word "civil" has no such distinctive meaning ; it only shows that civil engineering is the work of the citizen and not the work of the soldier. Civil engineering, in its true meaning, embraces every special branch of engineering. The professional limitation which should be applied to the civil engineer is that he must be a man who, in his own department, can design as well as direct ; he must have that control over his work which nothing but intelligent knowledge of the subject gives. He may be a railroad builder, he may be a skillful surveyor, he may be a mechanical engineer, or he may follow any other specialty, but whatever he does he must do it, not as a skillful workman, but as one qualified to design. Any man who is thoroughly capable of under-

standing and handling a machine may be called a mechanical engineer, but only he who knows the principles behind that machine so thoroughly that he would be able to design it or to adapt it to a new purpose, whatever that purpose may be, can be classed as a civil engineer. Any skillful sewer-builder and pipe-fitter may claim to be a sanitary engineer, but only the man who approaches his work with the intelligent knowledge of the conditions which sanitation involves can be classed as a civil engineer. Any man who knows how to work a mine may be a mining engineer, but only he who understands why he works his mine as he does can be called a civil engineer. Any well-practiced electrician may be classed as an electrical engineer, but only one whose practical knowledge is based on the intelligent study of electricity can be called a civil engineer. The business of every engineer is to handle tools ; the business of the civil engineer, whatever department or specialty he may follow, is to design and build those tools rather than to use them. I use the word tool in its largest sense ; you may call it engine if you prefer. Any constructed thing whose principal object is to produce something outside of itself is a tool, whether that tool be a bradawl, a steamship or a railroad. Civil engineering embraces all branches of engineering, but the civil engineer differs from other engineers in that he makes tools rather than uses them. The relation of civil engineering to all other branches is of the broadest kind ; no branch of engineering is excluded ; the only exclusion is based on the individual qualifications of the men.

The civil engineer is briefly a man who, with knowledge of the forces and materials around him, uses that knowledge in the design and construction of engineering works. His business is to design the tools by which the sources of power in Nature are directed for the use of man. A body of civil engineers should include the choicest minds in every branch of the engineering profession.

Our Constitution provides that a member shall be a civil, military, naval, mining, mechanical, electrical or other professional engineer, an architect or a marine architect, qualified to design as well as to direct engineering works. It would perhaps have been better expressed if it had said that any civil, military, naval, mining, mechanical, electrical, or other professional engineer, architect or marine architect who, with knowledge of the great sources of power in Nature, uses that knowledge in the design and direction of engineering works, is qualified to

be a member. We welcome into our Society all branches of engineering, but not all engineers. We welcome every engineer who applies a knowledge of the powers of Nature to the design and construction of engineering works; we welcome the architect who uses this knowledge in his designs and constructions, but the architect who treats his profession as a fine art to decorate a construction which he cannot design, belongs elsewhere. Intelligent knowledge of the great powers in Nature is the fundamental requirement for a civil engineer. On this substructure a superstructure of actual design and construction must be built to make the complete professional man.

The civil engineer of the new epoch, the epoch which he is bringing into existence by the manufacture of power, must be an educated man; in no profession will this be more necessary. The physical laws of power and strength are mathematically exact and admit of no trifling. As the epoch progresses the requirements for each individual will become more complicated. The theologian and the metaphysician may claim that an education based on the laws of matter leaves out the highest part of existence; the biologist and the physician may claim that matter endowed with life is a higher organism than the inanimate matter with which the engineer has to deal. But, however true these claims, their laws have not the mathematical rigidity, the clear definition and the thorough discipline which mark the laws with which our profession works. The engineer cannot shield himself under doctrines or theories which he accepts but cannot understand. Dealing with accurate definite laws and guided by the corrective touch of physical nature, the education of the engineer will become more necessary, more thorough and more exact than that of any other professional man. This is the training which the civil engineer of the new epoch must have. This knowledge he must have or he must be classed as a workman rather than a professional man.

The civil engineer of the new epoch must sink the individual in the profession. The engineering work of the future must be better work than has ever yet been done. The best work is never done by separate men; it is only accomplished when professional knowledge so permeates all members of a profession that the work of one is virtually the work of all. The first steps are made by individuals, but the best results come later. The name of Watt will ever be identified with the successful introduction of the steam engine, and nothing should be

allowed to belittle his reputation, but there are 10 000 men to-day, any one of whom can build a far better engine than James Watt ever could. They can do it because they are imbued with all the work the engine-builder has done for more than a century; they do it as members of a profession who are all working together. In the middle ages Gothic cathedrals were built throughout Northern Europe ; they are exquisite works ; no modern architect can approach their beauty; the reason is that the men who built the Gothic cathedrals worked together as members of a guild which was thoroughly imbued with the spirit of building these churches. In no period of the world's history has marine construction had any significance compared with what it has to-day, and it is because the great ship-builders are working together, each having the practical benefit of what they all are doing. They are working together as members of a profession rather than as individuals, and their work is becoming more uniform and more perfect.

The civil engineer of the new epoch must be a specialist. No man can learn to design all the tools by which the powers in Nature are to be directed. The work is too great for one man to master. The best results will only be obtained by concentrating effort in a single line. But though the civil engineer must be a specialist, his specialty must not be of a narrow kind; he must have that general knowledge and training which makes the liberally educated man. The real difference between a liberal education and a special education is that one teaches the student to use his mind and the other gives him information. The civil engineer must have had the mental discipline which qualifies the mind to investigate kindred subjects beyond the limits of his own specialty; his education must be broad enough for this or he will not be a civil engineer. The knowledge of his specialty will be only part of his education; the mental discipline will be more.

And, last, the civil engineer of the new epoch must fill many positions which are now held by men of different training. The knowledge of the tools, both large and small, which men are using, must be the strongest qualifications for their use. Accurate engineering knowledge must succeed commercial guesses. Corporations, both public and private, must be handled as if they were machines, and the men who will so handle them will find their best training in the education which will make the best civil engineers.

Having now considered what should characterize the civil engi-

neer of the new epoch, let us pass from the individual to the profession, from civil engineers to the Society which they have organized. The American Society of Civil Engineers is a national society, though its membership is not restricted even by national boundaries. There are many other engineering societies and associations in our country; some of them are national, some of them are local. A full consideration of the position which our Society should hold in the new epoch must not forget these other societies.

The objects of the American Society of Civil Engineers are defined in the Constitution to be "the advancement of engineering knowledge and practice and the maintenance of a high professional standard among its members," while the means to accomplish this purpose are broadly stated to be intercourse between members, professional papers and a library for professional use.

Intercourse between members is perhaps the most important of all. In no other way can the standard of a profession be raised so well. The man who works alone without measuring himself by others never does his best. The engineer must both measure himself by what others do and let others measure him. The time of cryptograms has gone by; there will be none in the new epoch. Intercourse between members will do more than anything else to fill the requirement of the new epoch and make the work of each engineer the work of the whole profession.

The preparation and publication of professional papers is another duty of the Society. There is an important difference between the papers which must come before a society and those which are published elsewhere. Other professional publications are generally, like architectural monuments, records of what has been done, published for the preservation of those records and not for much more. The fundamental feature of the papers of a professional society, on the other hand, is that, like every engineering work, they are tools. Their work begins when they are read; they are intended to bring out discussions, to compare different views, and in this way to give the knowledge of the profession to all. It is in this line that most development is needed. The papers which are now published in our *Transactions* are, many of them, very good, but the discussions are not what they should be. An author may be best satisfied by the paper which is most perfect in itself, but the paper which brings out the fullest

discussion is the most useful to the Society. We have an endowed prize for a paper worthy of special commendation as a contribution to engineering science; we have another endowed prize for a paper describing in detail accomplished works of construction. There should be a third endowment for a prize for the paper which calls out the best discussion of the year, and this prize should be given without reference to the awards of the other two, so that if the paper which receives the Norman medal also brings out the best discussion it will receive two prizes instead of one.

Our Society has a professional library, but the facilities for using it are far from what they should be and are a poor fulfillment of the constitutional requirement for the establishment of facilities for its use. Every book on an engineering subject ought to be found on our shelves soon after it is published, and engineers should find this library as convenient a workshop as the library of the Bar Association is to members of the bar. It should be open, not only during the daylight hours, but late into the evening, so that the older engineers, who have no time in the day, and the younger men, who have nowhere else to go in the evening, can realize the full benefit of its worth. In a new Society house separate and safe provision for the library must be given special attention.

It will be the duty of our Society to elevate the profession of the civil engineer to the very highest rank among the liberally educated professions. This is a duty of the day rather than a duty of the new epoch. When the new epoch is fully established it will have been done, and the Society will have become the conservator rather than the promoter of the profession.

Furthermore, the main principle of the Society should be the professional principle. It must secure the very best work which can possibly be done among its members—they must not be inventors working alone by themselves. It must teach them that they are members of one profession all working together, until that spirit of professional unity is established in which it becomes impossible for any member of the Society to do bad work.

The Society must work for the profession rather than for the individual; its duties are the advancement of engineering knowledge and practice and the maintenance of a high professional standard. It must not mix itself up with the affairs of individuals; it has no secret

rites nor arbitrary rules; with scales of charges it has nothing to do: it will not demean its members by putting itself on the basis of a labor organization. High professional standards can never be maintained by agreements which restrict the free right of the individual to receive such compensation, large or small, as his own ability has shown he is worth; they can only be maintained by that true professional spirit which sinks the individual in the whole.

The relations which our Society should bear to the other national engineering societies is established by the definition of civil engineering. Our Society should include the choicest minds in every branch of engineering; it must have among its members the leading members of every society which represents an engineering specialty. No other society can have our general range; on the other hand, no other national society can make the same restrictions as to individual requirements. Each of the other societies is devoted to some specific branch of engineering, but the individual qualifications should be comparatively light; it receives into its ranks every engineer working in its specialty, as we receive engineers of every specialty, but not every engineer.

The American Society of Mechanical Engineers accepts as a member any one who is "competent to take responsible charge of work in his department"; it is not necessary that he should be able to design, and while this would be a bad provision for our Society, it is exactly right for the Society of Mechanical Engineers. We take in the educated men of every branch of the profession; each other national society takes in every man who is devoted to the specialty which that society represents. There can be no conflict between those societies and ourselves; it may be hoped that in time every one of our members will belong to at least one of these other societies.

The relation which our Society is to bear to the various local societies is of a different character. These societies are intended to bring together the engineers of the immediate neighborhood in which they are established. Their opportunities for social intercourse and for frequent discussions are necessarily greater than those of a national society. Their requirements for membership should be more liberal than those of any national society. Like our Society they should receive members from every branch of engineering; like the mechanical and other special societies they should admit every one who is qualified to take responsible charge of work in his department. The quali-

fications for a member in the Western Society of Engineers, the Chicago local society, are simply that he must have been engaged for five years in some branch of engineering. It would be an appropriate thing for those local societies which now have it in their title, to drop the "Civil" and let them all become "Societies of Engineers," restricted only by convenience of location.

The relation of our Society to societies of the other classes, may, perhaps, be likened to the three dimensions of space. Our society has a length which is defined by no geographical limits and a breadth which is bounded by no engineering specialties, but its depth is limited by the qualifications of individual men. The other national societies have the same indefinite length that we have, but the breadth is limited to the specialty which characterizes each one of them, while the depth is unlimited as they take in every engineer who follows this specialty. The length of the local societies is confined to the geographical limits which they represent, while the breadth and the depth are both unlimited.

As the national societies all have their quarters in the same city, any engineer residing in or near New York may find all that he needs in one or more of the national societies, but it is hoped that in time every non-resident member will also be a member of one of the local societies.

The differences between our Society and the several other classes of engineering societies are of so radical a nature that it would be a dangerous thing to try in any way to consolidate or unite them. We cannot unite without entirely changing the qualifications for membership. No idea of uniting with the other national societies has ever been suggested. We cannot unite with the various local societies without either so widening the qualifications of our membership that we shall cease to be a society of civil engineers, or so restricting the qualifications of their membership that the ranks of many of them would be destroyed.

But, though we cannot unite with any of the other societies, it is our duty as the leading engineering society of America, and one of the leading societies of the world, to treat all other technical organizations with the same generous kindness and courtesy which should characterize the treatment of gentleman by gentleman, of professional men by each other. The members of the different local organizations

should be welcomed to our headquarters and we should freely exchange our publications with other societies, esteeming it a privilege if we are able to give them more than they give us.

Passing from general considerations to actual work. Engineering tools may, for convenience, be classified on the basis of their approach to the manufacture of power. The first place may be given to the tools which manufacture power; the second place to those which transmute power; the third place to those which transmit power, and, after this, the rank and file of miscellaneous tools may follow.

The only tool in general use for the manufacture of power is the steam engine, but the caloric engine had its field of usefulness, while gas engines and oil engines are doing good work where small installations of power are needed. An engineer who was lately one of our ablest and most active members, Mr. A. M. Wellington, was engaged at the time of his death in the perfection of a thermo-dynamic engine of novel design.

The tools which transmute power are principally two, the water-wheel and the windmill. The water-wheel has been brought to a degree of perfection scarcely equaled by any other tool; the windmill is still a crude and usually a badly made affair. The last year has seen at Niagara, the installation, not yet completed, of the largest water-power plant ever erected.

In tools for the transmission of power the progress of the last few years has far exceeded all that had ever been done before. So long as engineers sought to utilize electricity to manufacture power they failed; but when they adopted it as a means of transmitting power, the results became superb. The dynamo, though logically a tool to transmute power, is practically more properly classed as part of the general tool for electric transmission of power.

Without attempting an exhaustive division, three classes of the more general tools may be mentioned.

The first of these are tools of transportation, of transportation by land, and of transportation by water.

By land, the steam railroad system has become a tool of such magnitude that to many it has seemed as if no man could be a civil engineer unless he were also a railroad builder. The wild extensions built rapidly and carelessly through unsettled territories, or with less rapidity and greater carelessness where not needed in the older dis-

tricts, are nearly done ; but an immense work remains in improving terminals, developing better local facilities and generally bringing these great railroad tools into a condition in which they will perform their own duties better and interfere less than now with other work. In a distant part of the world a railroad is building which cannot fail to have a great influence in the new epoch. Twenty-six years ago the American continent was first crossed by a railroad reaching from ocean to ocean; seven years hence the Trans-Siberian railroad will complete a continuous line across the older and greater continent, eastward instead of westward, from the Atlantic to the Pacific. This new railroad, passing around the most populous portion of the globe and the seat of a civilization now farther than any other from the conditions of the new epoch, may do more than any one thing to render that epoch universal. In about a century from its first general introduction manufactured power will have crossed both continents, and by the aid of manufactured power on the ocean it will be possible to make the circuit of the globe in about 40 days. The extension of the electric railroad system, especially in our cities, has been rapid, until now there are in this country not less than 10 000 miles of railroad operated by electricity. In Chicago the newly opened Metropolitan Elevated Railroad, the best designed and most thoroughly constructed road of this kind yet built, uses electric motors.

In transportation by water two very important works belong to this year, one completed, the other as yet no more than considered. The first is the North Sea Ship Canal, which, passing through the northern part of the German Empire, connects the Baltic with the North Sea. The second, of more importance to Americans than any water project started since the conception of the Erie Canal, is the Nicaragua Canal, the completion of which, besides opening a new general waterway, will make the Atlantic coasting fleet available for the coasting service of our whole country. A board of three engineers, all members of this Society, is now in the Isthmus engaged in an investigation which we all hope will justify the early construction of this great work.

The waterway and the boat that navigates it are equally tools of transportation. The advances in marine engineering and especially in the ocean marine have been most marked, the development being both in the manufacture of the hulls, which are now almost invariably built

of steel, and in the development of higher steam pressures through the compounding of engines, until the latest addition to the fleet of full-powered ocean steamers, the *St. Louis*, built at Philadelphia, carries a steam pressure of 200 lbs. and develops her power through two quadruple expansion engines. The advances in lake marine have been almost as great as those in the ocean marine, but all this time our western rivers are navigated by boats which differ little from those which ran upon them 50 years ago. They still have the wooden hulls, the long-stroke high-pressure horizontal engine, the big separate side wheels, and the battery of small boilers; their machinery is a little better than it was at first, the pressures they carry a little higher, but the changes are so slight as to be insignificant. The channels of the principal western rivers are being constantly improved under the direction of the general Government, but as yet no response has been made to these improvements by the radical improvements which ought to come in the boats and their engines. Much is said of the decline of river business—it has declined because land transportation has given better and cheaper facilities. Until the boats on the western rivers make the same advance that other tools of transportation have made, this business must continue to decline.

Another very important class of tools are the sanitary tools. The history of the world is filled with stories of pestilence which could have been avoided entirely by proper attention to drainage and water supply. There is no branch of engineering which is so directly associated with the convenience of man. The larger sanitary tools, unlike the tools of transportation, are generally constructed by public and not by private corporations, and this makes it necessary to build works which the public can understand, where the educated civil engineer may feel that a different thing would be better. The most important work of this kind now in progress is the drainage canal building by the Sanitary District of Chicago, intended to divert water from Lake Michigan to the valley of the Illinois River in sufficient amount to form a clear flowing stream which will not be polluted by the sewage of a great city. This work has now progressed to such an extent that it is expected that the water may be admitted to this new channel before the end of 1896. The work is a very remarkable one, and one which, under the present condition of things, was absolutely necessary to insure the health of the great city of the lakes. But every tool is

likely to be superseded by a better one, and it is somewhat doubtful whether future engineers will consider a tool which washes away the sewage of a city an intelligent solution of a problem of this kind. The canal will be worth all that it costs, but it is not unlikely that another generation will see means adopted to keep the sewage out of the channel which has been built to dispose of it, and will utilize it on the sandy district south of Chicago.

The other classes of tools need be referred to but briefly. Among them are the tools for general commercial uses, such as warehouses and office buildings, in which a decided change has taken place within a very few years. Heavy masonry walls are being discarded in our large cities and skeleton structures of iron and steel are being adopted as the most convenient and economical tools. These buildings must not be confused with the great monumental buildings of the world, they are tools rather than monuments; their construction belongs to the engineer rather than to the architect. They are still marred by inappropriate decorations patterned after masonry construction, but the method of construction has been adopted because it gives economical results, and so with least expenditure of money produces a tool of greatest profit. The durability of oxidizable metal may not be that of masonry; it remains to be proved how durable these buildings are, but as economical structures they are excellent tools. It is interesting to note that in New York City not only is metallic construction being applied to all commercial buildings, but the same methods are being used for the foundations of these buildings that have been proved to be most efficient under great bridges and works recognized as strictly of an engineering character.

Another tool which is about approaching completion and which is being executed under the direction of engineers is the Congressional Library at our national capital. This library building, designed expressly for the purposes of a library, to take care of books and provide for their use, is built on engineering principles, as a tool adapted to its purposes, ornamentation being made subservient to construction and decorated style secondary to use.

We have met at this convention in the oldest part of our country, in the harbor of a great city whose origin distinctively antedates the beginning of the new epoch. Boston was founded 139 years before Watt perfected his steam engine; it existed for nearly 200 years before

the general manufacture of power. In the later centuries of the new epoch it will be regarded as a city of ancient origin. In this community are men whose rank is among the very highest in the design of the highest class of tools, the engines which manufacture power. The leading hydraulic engineers of the country, whose business is to transmute power, have lived here. The Boston local society is the oldest engineering society in America. It is the section of our country which boasts the oldest university, the largest public library and the greatest proportion of educated men; and yet it is, perhaps, more necessary here than in any other part of the world to emphasize the real nature of our profession. I speak as a son of Massachusetts who, though much of his life has been spent elsewhere, has never wholly separated from New England. The ideas of the old epoch were strong; it was hard for the people of Massachusetts to recognize the importance of the civil engineer; the prejudices of the Puritan and of the old-time liberal professions were inherited from the past. There was not always a full conception of the real meaning of the construction of tools. Yankee ingenuity was thought enough to meet all requirements, and men of liberal education justly considered that work which native ingenuity did without training could not be ranked as professional work. Such men did not appreciate the civil engineer because they did not understand his work; they missed the distinctive requirements which make the civil engineer and confounded the profession with men who did not belong to it. Let it now be known distinctly that our profession is one of training and education. The civil engineer is an educated man, whose knowledge of the sources of power in Nature enables him to direct them for the convenience of man.

The tools which we have to build are generally large. The physical man is often a tiny thing beside the work which he has to construct. Nothing illustrates the power of mind over matter better than the work of our profession. Though we deal with matter and our work is of a material kind, it is the mind which has made this matter give forth power, it is the mind which is opening the new epoch, and it is by the training of this mind that the civil engineer must prevail. We are the priests of material development, of the work which enables other men to enjoy the fruits of the great sources of power in Nature, and of the power of mind over matter. We are priests of the new epoch, without superstitions; but, if our profession is to do the good work of which

it is capable, the true spirit of individual immolation which has characterized the devoted priest of all ages must be found among ourselves. The profession can only do its future work by trained minds working together.

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PAINTING OF IRON STRUCTURES EXPOSED TO WEATHER.

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READ MAY 1ST, 1895.

WITH DISCUSSION.

A great deal of thought has been bestowed on the subject of preventing rust on iron structures of all kinds, more particularly those exposed to the action of the elements on land and at sea. It is not intended in this paper to consider iron structures exposed to the action of sea water, but to confine the subject to structures on land.

Much has been said and written in the last few years about the worthlessness of iron oxide as a pigment in paints used for coating iron, and it is even extensively claimed that such a pigment is an active agent in producing rust on metal covered with it. On the other hand it has been said that red lead is beyond question the very best pigment to use, and much favorable comment has been given to paints composed, partially or wholly, either of carbon or its compounds. The objection against iron oxide, stated briefly, is that much of it is manu-

factured from iron by the action of some sulphur compound, and on account of this the oxide is supposed to contain sulphur which acts injuriously on iron. It is said to be an unstable compound, absorbing oxygen readily and conveying it to the metal which it is intended to cover. It is further said that oxide of iron paints are porous like a sponge, and without any action on the part of the ingredients of the paint, permit the air to get at the metal which they are supposed to cover.

It is claimed for red lead that it forms a chemical combination with the oil with which it is mixed, and that when properly applied to iron, it adheres with unusual firmness and makes an absolute covering which is impervious to air and water.

Carbon paints, including asphalts, are said to be chiefly valuable from the fact that the pigment can usually be more finely subdivided than other materials, and the carbon itself is chemically neutral to the iron.

It has been the custom for many years of George S. Morison, M. Am. Soc. C. E., to paint large iron structures with a mixture of pure iron oxide, consisting of a natural iron ore, simply ground without roasting, and pure linseed oil, and the results had been considered very satisfactory. During the past year, however, the officers in charge of one of these bridges became alarmed by the appearance of rust on the structure, both externally and under the paint, and were afraid that the iron oxide in the paint was the direct cause of this rust, owing to the supposed presence of sulphur in the oxide. On account of the supposed general injurious tendency of this class of paint, Mr. Morison decided, therefore, to make some investigations, and the author was instructed to examine the visible condition of the paint and the condition of the metal under the paint on the bridges at the following places:

Cairo,	Nebraska City,	Sioux City,
Memphis,	Plattsmouth,	Minneapolis,
Leavenworth,	Omaha,	Winona,
Rulo,	Blair,	Burlington.

In accordance with the instructions the author made the examination early in December, 1894. Considering the season of the year the weather was unusually favorable, the temperature being such that no discomfort was experienced in the examination of a single structure.

In addition to the structures mentioned above, as many others were examined as were readily accessible in the time allowed for the work.

The course pursued in making the examination was about as follows:

Most of the structures being through bridges, the author usually passed along the floor on the north side examining the end posts inside and out, the vertical posts and diagonals so far as they could be reached from the floor, and the tops of the floor beams and stringers. At each pier the pedestals, floor beams and stringers were carefully examined, and after thus passing over the entire structure along one side, the return trip was made along the south bottom chord in one span, from which the eye-bars of the lower chord, the floor beams and the stringers could be readily inspected; then generally over the top chord of another span, examining at the same time the cross-frames or sway bracing and the lateral bracing. The trip over the top chord was omitted in several instances owing to high winds and wet weather; this omission, however, was not of great importance, inasmuch as the condition of top cords could generally be predicted from the condition of the end posts, all of which were carefully examined on every bridge.

The paint was scraped off in numerous places with an old file ground to a chisel edge, with an angle of about 70°, this kind of scraper proving the most efficient after a number had been tried. The time devoted to the work was not sufficient to examine each individual member; it is believed, however, that no more information could have been gathered in any more prolonged investigation.

The examination was subsequently extended considerably, embracing structures in St. Louis and Chicago, and the total number examined is nearly 60.

The following observations were made at the different bridges in the order in which they were examined:

Cairo Bridge.

The Cairo Bridge was erected in 1888 and 1889, and the painting finished in the latter year. The bridge proper had been given one coat of hot boiled linseed oil, and the approaches one coat of pure iron oxide paint in the shop. The bridge proper was repainted in 1893 with one coat of the same iron oxide paint; the north approach was repainted in 1894 with one coat of the same paint, mixed, however, with lampblack,

to make the color black; and the south approach was repainted in 1894 with a coal tar paint. The bridge, having been so recently repainted, was in very good condition externally, no rust spots being visible anywhere on the surface.

On close examination it was found, notably on the end posts, that there were a number of little spots a little brighter than the surrounding paint, and under these bright spots rust was found. There were also in many places appearances of lumps or blisters under which there was rust; both kinds of spots were easily recognized. The bright spots were most prominent on surfaces exposed to both sunlight and rain, but were likely to occur anywhere, and were found even on the inside of end posts, though not often. The other lumps were usually due either to scale or actual blisters in the paint, indicating that they might have been avoided by a little scraping. In some places it was apparent that no scraping was done at any time, inasmuch as the original mill scale could be scraped off very easily. In such places it was not unusual to find that oil had penetrated under the scale and was often almost liquid, even after five years' exposure. Wherever scale appeared there was likely to be some rust; this was usually of a bright yellow color and was apparently only a thin film which could readily be rubbed off. The little bright spots seemed to be active rust centers, and if these were carefully examined with a magnifying glass, it would probably be found that the paint was cracked and that air and moisture could get in through it.

The paint usually adhered well to the metal and was very tough. The surfaces not exposed to sunlight and rain were in much better condition than the others; this is especially true of the floor system.

The condition of metal under paint here was not examined as carefully as on subsequent bridges for lack of experience as to what to look for. Generally, however, on scraping the paint from spots which indicated rust, the limits of the rust spots were soon reached and bright metal found under the paint.

On the Illinois approach, which had been thoroughly scraped on repainting, there was little visible indication of rust. Several places were scraped which showed the metal to be quite clean.

On the Kentucky approach indications of rust spots were found in the shape of blisters, etc., and on scraping these, rust was found to the limits of the blister, but beyond this the metal was clean.

Memphis Bridge.

The Memphis Bridge received one coat of iron oxide paint in the shops, and two coats of the same paint after erection in 1892.

The author first examined the east approach floor from below. There were some large spots on the lower flange angles of stringers, which, it was thought, were rust on the metal. Upon examination this proved to be drip from the floor above and was outside of paint, and had in no wise affected the metal. The condition of the paint on the floor was excellent, and on surfaces under the floor, where the sun could not penetrate, it was as bright as when put on, and was in most places still soft.

A number of rust spots and blisters appeared on the legs of the tetrapod on the anchorage pier; on the upper part, however, which is more or less protected, these spots did not occur. The anchorage bars were in good condition. The wedge blocks and wedges had a few rust spots on the machined surfaces.

On the bridge proper a few rust spots had developed on the horizontal surfaces, a less number on the upper surface of inclined members and practically none on the vertical surfaces, especially where these were not exposed much to sunshine and rain. On upper side of the inclined end posts and of the portals, the rust spots and blisters of paint were perhaps more numerous than on other inclined members, and on the top chord of the intermediate span, which was the only one examined, these were developed to a somewhat greater extent than on the corresponding end posts. The rust spots were of a dark brown color, and oxidation was in progress.

The floor system throughout the entire bridge, so far as observed, was in as good condition as under the east approach, and the metal under the paint was also generally clean; rust spots were found however.

In general the paint, where not exposed to sun and rain, was about as good as new and not yet dry and hard. Where it is exposed to sun and rain the paint was hard, adhered to the iron very tenaciously, and was exceedingly tough. While there were rust spots visible in a good many places, the bridge on the whole was in very satisfactory condition.

This superstructure was manufactured by several different bridge companies; there was no difference observable, however, in the condition of the paint on the parts made by different firms.

Many of the rust spots were scraped, and beyond the limits of the visible spot there was usually clean metal. At times a thin film of yellowish rust extended some distance beyond the spot, but this was very thin, was readily brushed off, and did not appear active.

Where no rust spots were visible, the metal was usually clean and bright under the paint, although occasional rust spots were found, as, for instance, on lattice bars and webs of stringers.

It was quite noticeable that wherever the surface appeared perfectly smooth there was little likelihood of any rust being found under the paint. On rougher surfaces, or those that were originally scaly, more rust was found. Plates were much smoother than shapes, and also much less rusty under paint. This same feature was noticed at Cairo.

The fence throughout, especially on the channel which forms its top, had a great number of little blisters or scabs, under all of which there was rust of a brown color. These were all open to the atmosphere and were evidently active rust centers; where this eruption did not appear, it was still the rule that rust was found under the paint, but it was generally of a bright yellow color and did not appear active. On scraping the latticing, yellow rust was generally found.

The shop inspector reported that the lacing and Z bars of the fence were pretty rusty before being manufactured; the channels on the top, however, were comparatively clean.

On the west approach viaduct the horizontal members near the ground had rusted somewhat on their upper horizontal surfaces. The vertical and inclined surfaces were in very good condition, and so far as scraped, were generally clean under the paint. The horizontal members higher up were practically free from rust on the surface. The lacing was at times rusted under the paint.

Leavenworth Bridge.

This bridge received a coat of oil in the shop, and two coats of pure iron oxide paint after erection in the summer of 1894.

The external appearance of the paint was exceedingly good. It was faded somewhat where exposed to weather, but was bright and glossy in other places and was in good condition physically everywhere. It was usually tough and adhered very firmly to the iron. It was not thoroughly hardened on any part of the bridge, even where exposed to the sunlight.

Wherever the iron was much pitted, or where scales or blisters were indicated, there was likely to be rust under the paint, and where the metal had a smooth appearance there was none. The shapes showed rust oftener than the plates, although some of the lattice bars of the vertical posts were very badly pitted, and these were rusty under the paint. It was known that these were rusty before leaving the shop, and it was noticeable that the oil which was put on there had soaked into the rust wherever this amounted to anything, and had practically made a paint of it. Under the scale, more particularly on the eye-bars and heavy angles, it was not uncommon to find oil in almost a liquid condition. The outside of the drum was pitted more or less and showed rust under the paint, although this was generally soaked full of oil. On the top chord there was no indication of rust, either on the surface or under the paint. Other members on the top seemed to be in equally good condition. So far as rust was found under paint, it was evidently not in an active condition. While rust was found in spots under paint on almost all kinds of surfaces, it was nevertheless the exception, the rule being that the metal was clean.

After examining the bridge, the author went to the shops of the Missouri Valley Bridge and Iron Works, which were close at hand, and observed the work which was then in process of manufacture. Much of it had a small amount of rust on its surface, in irregular spots and of the same thin, filmy character and yellow color as was noticed both on the Leavenworth and Memphis Bridges. This thin film could be readily wiped off, and some little blisters which had developed could be scraped off. The blisters undoubtedly formed the rust centers, which, after painting, soon broke through and became visible rust spots; and the yellow film of new rust, which could be readily wiped off, was apparently what was to be found under the paint on the surfaces, which otherwise seemed to be in good condition.

Rulo Bridge.

The Rulo Bridge received one coat of oil in the shops, and after erection, two coats of iron oxide paint in 1887. It was repainted in the summer of 1893 with one coat of Cleveland iron-clad paint, applied without previously scraping the metal.

The visible condition of the paint on the bridge was excellent, no rust spots being seen anywhere. The paint was generally tough and difficult to remove.

On the top chords of the west deck span there were numerous little lumps indicating blisters, and these were sure indications of rust under the paint. Outside of these blisters rust was not so certain to be found, although it was not always absent. These blisters were, no doubt, caused by earth falling off cars and lying on these chords for a long time. Earth was hauled over the bridge for several years to fill the east trestle. On the vertical plates of the chords there were few of these blisters, and the metal under the paint was generally clean; the same was true of the floor beams and stringers. The cylinder caps had some blisters, which showed rust when scraped; aside from these, the metal under the paint was generally clean. The posts carrying deck spans were also quite free from rust spots under the paint, and in many places where there was some scale on the iron, practically liquid oil was found under this scale.

On the main spans few places were scraped which did not show more or less rust under the paint. On the cover plates of all end posts and portal plates that were examined, there was rust under the paint. Where the exterior was smooth, this was comparatively little; but where rough, there was more. The rust was evidently in spots, as clean places were often met with next to the rust spots. On the inside of posts where the paint was comparatively soft, there was much less rust under the paint than outside, but it was found nevertheless. The web plates of stringers and floor beams were in no better condition than the inclined cover plates, and the horizontal plates on the stiff bottom chord were no worse than the stringers. In stiff lateral bracing the top surface of a particularly smooth angle was quite decidedly rusty under the paint. Every vertical post examined had rust under the paint on the exposed surfaces. Several that were examined on the inside showed clean metal.

The tops of floor beams were in worse condition than any other portion, there being a great deal of rust under the paint. These evidently were not scraped when the bridge was repainted, and here was about the only place where paint could be scraped off easily. The tops of stringers were in much better condition than the tops of floor beams. On one end floor beam a mark painted in the mill with white lead was found, and under this there was no rust. On another floor beam a shop mark in white lead was found, under which there was some rust.

On one end post between the upper and lower flange angles on the side plate a large quantity of oil had collected, was still soft, and had subsequently been painted over. There was rust under this oil.

There was no regularity as to where rust might be expected under paint. It appeared almost everywhere, and clean metal was the exception rather than the rule. Smooth surfaces seemed to be no better than rough ones, and exposed surfaces no worse than those protected.

The bridge had been thoroughly scraped before the first coat of paint had been put on, and the shop inspector reported that the metal in the shop was comparatively clean.

Nebraska City Bridge.

This bridge received a coat of oil before leaving the shop, two coats of iron oxide paint after erection in 1888, and was repainted in 1893. The visible condition of the paint was excellent throughout.

On examining the cylinder piers on the east side, rust was found under paint on the south cylinder, but the north one was clean. These cylinders were originally a part of the Omaha Bridge, and were erected there about the year 1870. They had evidently always been painted with iron oxide paint. The end posts and portals of the deck span were comparatively clean under paint, although now and then a rust spot was encountered. The vertical posts on cylinder piers were also quite free from rust under paint. The top of the upper chord was rusty in spots. Much earth had been hauled over this bridge to fill trestles, and this work was in progress at the time.

The fence throughout the bridge was generally found clean, this applying to angles, tees and lacing, without distinction.

On the main spans the end posts, portals, intermediate posts and eye-bars had few rust spots under paint, and the surfaces of these members were all very smooth. The intermediate posts are built from angles and plates. On the inside of the end posts the paint was still soft, and a few rust spots were found under it. The floor beams and stringers looked well, but more rust was found under the paint than on the posts. The stiff bottom chords had some rust spots under the paint, but were clean on the whole. The top of the cover plate of the upper chord showed more rust under paint than other members. In all classes of members the rust was found to be in spots.

The surface of the metal in this bridge was generally very smooth, and few blisters or lumps were found indicating scale, nor was the metal pitted to any extent.

On a through plate girder a short distance from the bridge, the paint was in good condition, so far as external appearances went. It was built at the same time as the main bridge, painted in the same manner, and undoubtedly repainted at the same time. The metal on the web plates was usually clean; on the cover plates and floor beams, on the contrary, it was usually rusty under paint.

A bridge over the Missouri Pacific Railroad was built in 1888 in connection with the main bridge. It was originally painted next to the iron with a reddish paint, and it was rather difficult to distinguish between this paint and rust. Subsequent coats were of the iron oxide used on the main bridge. There were some spots of rust found under paint in various places.

At no place where rust was found on the Nebraska City Bridge and the smaller structures on the approach was it of any great extent in depth or area. It was generally of a yellowish color, and when exposed by scraping could be easily wiped off, leaving bright iron as heretofore noted.

Plattsmouth Bridge.

The time devoted to this bridge was rather limited. The bridge was completed in 1880, was painted with the usual kind of iron oxide, and is reported to have been painted on an average every two years since with the same iron oxide paint, the last coat being given it in 1893. It looked as if it had not been scraped after the first painting, and as if the paint had been applied on the theory that the larger the quantity, the better the job. The external appearance of the paint was good, except that it was lumpy in appearance from the quantity put on, and re-entrant angles had become curves of appreciable radius. A few rust spots and blisters were visible, principally the latter.

On the west bent of the west approach viaduct the paint adhered well in some places and in others it peeled off very readily, owing, no doubt, to its thickness and the fact that it had never had an opportunity to dry thoroughly. Under the paint the iron was very clean. On the inside of one post a strip of paint 8 ins. in length was peeled off without showing a single rust spot, and the metal looked as bright as if it

had just come from the mill. The stringer webs of the viaduct were in excellent condition under the paint.

On the end posts of the west main span the metal under paint was rusted very badly, the paint was thick and soft, and in places there were large blisters of long standing under which there was rust. Immediately adjoining one of the largest blisters, perfectly clean metal was found under very soft paint. On machine-finished surfaces on the pedestals there was comparatively little rust under paint. The vertical posts were in better condition than the end posts, many being found quite clean under the paint, and those where rust was found were not bad. The flanges and lacing of these posts were generally in worse condition than the backs of channels. The eye-bars were in fair condition, most of them being clean, although some rust was found. On one bar a spot of red paint was discovered next to the metal. This was apparently red lead, and under this there was no rust. The inside of the end posts, so far as examined, was much better than the outside. The top of the floor beams was unusually clean under paint. The upper chord looked well, but on scraping there was dark-colored rust found under the paint. Here the paint adhered to the iron very well, and the rust was such as did not appear at all active. The lateral struts immediately over the stacks of engines were very black, but the paint under soot was in good condition and the iron under it also. Darkness prevented any extensive examination of the top chord, or of anything but main spans.

Wherever rust was developed under the paint on this bridge, it was quite bad, but this could usually be readily traced to blisters or other causes. The paint had evidently been put on top, thick, and had not dried well, and, therefore, scales and blisters had formed. A blister when once developed is very likely to open somewhere to the atmosphere, and rust is the inevitable result. The sticking qualities seemed not as good with this thick paint as with thinner coats. Wherever the paint was found thoroughly dry, the adherence was all that could be desired.

Union Pacific Bridge, Omaha.

The Omaha bridge received a coat of hot boiled oil before leaving the shop, and two coats of iron oxide paint after erection in 1887. The rust spots that appeared on it were touched up about two years ago, and the entire bridge was repainted with two coats of iron oxide paint

in July, 1894, special pains being taken to scrape the old paint before new was applied.

The external appearance of the paint was excellent. There were neither rust spots, blisters nor daubs of paint visible, it adhered well everywhere, and it was generally smooth.

Under the paint rust was found wherever roughness on the exterior indicated it, and occasionally under the smooth surfaces, but the latter was exceptional.

The tops and sides of end posts and webs of stringers and floor beams were generally clean, rust spots being very rare. The sides of pedestals were equally clean. A few rust spots were found on the under sides of the cover plates of end posts; the inner sides of side plates, however, were clean.

The channels of the intermediate posts were usually found rough, and on these rough surfaces rust was often found. Wherever the surface was smooth, no rust was likely to be found. On the insides of these posts the metal was usually clean. Lattice bars were clean or rusty under paint, as they appeared smooth or rough. The eye-bars were unusually smooth and were clean under paint. The tops of floor beams and stringers, so far as examined, were about equally divided between showing rust and being clean under paint. In a few places where quantities of paint had been spilt, and this was not yet dry, there was usually considerable rust which appeared active.

On the deck spans, of which the east ones were examined more particularly, the top of the upper chord was quite rusty under the paint. This is said to have been very rusty before the recent painting, on account of an accumulation of earth from trains filling the trestle. Webs of stringers and floor beams were clean, as was also the upper side of the lower flange angles. Vertical posts carrying the spans were quite clean under the paint. The cross-struts showed some rust on the upper sides, but this was only in spots. The cylinder piers were examined on both sides of the river. They were apparently painted originally with red iron oxide; this adhered exceedingly well to the iron, but there were also rust spots of the same dry filmy character found under this as elsewhere.

The fence is said to have been quite rusty before the last painting. It was found, however, that where the metal looked smooth, it was clean under the paint. The rust which was found, unless it was under old

scale or heavy paint spots, was in thin yellow films, which could be brushed off readily, leaving the iron in good condition, and this rust was apparently doing no harm.

It was again quite noticeable here that plates were in better condition than the rougher shapes.

Omaha Wagon Bridge.

The wagon bridge at Omaha was originally painted gray, and subsequently of a yellowish color almost white. The yellowish paint was put on in 1893, while the other was applied about 1887. It is not known what this paint was, but presumably it was a white lead, colored. It adhered well to the iron. There were practically no visible rust spots, although the paint looked very dirty.

Under the paint the vertical posts carrying the viaduct were generally clean, the plates being better than the shapes and the horizontal members being more rusty than the vertical ones. The cylinder piers on the edge of the river were scraped in spots and the metal found to be clean. On the main span the cover plate on the end posts showed some rust spots, both inside and outside, though these were not bad. The intermediate posts and eye-bars were generally clean, but rust spots were occasionally found in all localities. On the east end post a red spot was discovered under the paint which was apparently red lead, and under this rust was found.

The rust spots under the paint on this bridge were usually of a dark color as distinguished from the yellow found elsewhere. They were, however, not at all active, being apparently somewhat oil-soaked.

Chicago and Northwestern Plate Girders.

In Council Bluffs, several plate girders belonging to the Chicago and Northwestern Railway were examined.

The Chicago and Northwestern Railway Company uses an iron oxide paint manufactured by the company from iron ore by roasting and grinding and mixing with pure linseed oil. This differs from the paint used by Mr. Morison in that the ore is roasted to drive off sulphur. The oxide of iron used by Mr. Morison contains no sulphur, as will appear later.

On the web plates the peculiar little blisters or eruptions noticed on the fence at Memphis were observed with the usual results, viz.,

that actual rust centers were under these. These little eruptions were not observed on any structure after leaving Memphis. Aside from these the plates seemed to be clean under the paint. The angles and cover plates showed some rust under paint.

East Omaha Draw Bridge.

This bridge was apparently painted with red lead at the shops and subsequently painted gray, and the finishing coat a yellow. The painting was probably done in 1894. The external condition of the paint seemed excellent, although it was beginning to look somewhat dirty. Under the paint the iron was usually clean, though some old rust spots were found on members in almost any position. These spots were again dark and inactive. It was very difficult to scrape off the red lead, and, on this bridge at least, it adhered as well as, if not better than, the best iron oxide so far observed, and it was also quite tough.

Blair Crossing Bridge.

This bridge was given one coat of boiled oil in the shops and two coats of iron oxide paint after erection during the early part of the summer of 1884. The work was done under the direction of the author, and while care was taken to clean the metal thoroughly, to avoid wet or freezing weather, and in general to make a thoroughly good job, it is not believed that the treatment was any better or differed essentially from that of other bridges built by the same chief engineer. The bridge has not been painted since, except in a few spots near the floor.

The end post, upper chord, lateral struts and rods all showed a good many rust spots, most of which were comparatively small individually, but were often gathered in clusters, making it look worse than it really was. There were also, however, some large spots. On the intermediate posts the channels were rustier than the lacing, the latter being in very fair condition. The east side of the intermediate posts and the end posts facing east were apparently worse than the others. The eye-bars and the floor system were quite free from rust. The ends of floor beams were somewhat worse than that portion protected by the ties, which was in exceptionally good condition.

The paint was faded to such an extent that it had somewhat the appearance of stove blacking, except that the color was grayish brown,

its adhesive qualities were exceedingly good, and it was very difficult to scrape it off at all where the original iron had been free from scale. In this respect the paint on this bridge was quite equal to, if not superior to, the red lead on the draw bridge at East Omaha. In the outer surface of the paint on the exposed surfaces, the oil seemed to have entirely disappeared, and there was a thin film of dry paint which could be rubbed off; when this was done the original color was practically restored. In going to the top chord, the author went up the end post, and the prints of his feet over the rivet heads were distinctly visible.

The rust spots were noticeably more numerous on the exposed surfaces than on others, except that on the interior of intermediate posts occasional large scales of rust were found, these being undoubtedly due to the original scale on the inner face of channels. On the east end posts there were a few spots, where paint had evidently been rubbed off when it was still fresh, which showed perfectly clean, bright iron. It is very likely that the original coat of oil put over this iron was still intact and preserving the metal.

As for the condition of the metal under paint, wherever no rust appeared on the surface of plates, including the cover plates of end posts, portals and top chords, the metal was usually clean, and where a rust spot was found it was of a bright yellow color, very thin and apparently not at all active. On the channels of the intermediate posts more rust was found under paint, and this was more common on the flanges than on the back of the channels. The inside of the channels was usually clean, with the exceptions mentioned above. The lacing was quite clean, and in some places where the flanges of a channel were rusty under the paint, the lattice bar immediately adjoining and within 3 ins. of it was perfectly clean under the paint. It was again noticeable that more rust was found under paint on the shapes than on the plates, and the eye-bars again were apt to be found clean. The webs of stringers and floor beams were particularly clean, and the paint on these was hard and very tenacious.

The top chord of the west approach span was somewhat rusty under the paint. The girders leading from the west end of the west approach span to the bank had at one time been painted with asphalt over the iron oxide paint and partially buried in the ground; the metal under this asphalt paint was perfectly clean, although the asphalt had

shriveled up and was peeling off, leaving the iron oxide again exposed to view.

The cylinders under the east approach span were badly rusted on the sheets next to the ground; the upper ones were in much better condition.

Considering the length of time that this paint had been on, it had lasted uncommonly well and preserved the structure admirably, and the existing condition of the sound paint was quite remarkable for its hardness, its adhesive qualities, and at the same time for its toughness. When the bridge is repainted it will be necessary to scrape it thoroughly, but it would be exceedingly unwise to scrape off the paint which now adheres, as no better adhesion can ever be expected. The paint having been on 11 years without rusting the metal, in fact preserving it so well, it is probably safe to leave it on, covering it, however, by a new coat of the same material, which will probably be done soon.

The bridge was wet in the morning, and, on scraping, after wiping off the water as much as possible, it was noticed that water had penetrated into the paint very slightly.

Sioux City Bridge.

This bridge received a coat of boiled oil in the shops and two coats of iron oxide paint after erection early in 1889; it was repainted in June, 1894, with a patent paint, which is an iron oxide of a reddish color and has considerable gloss. How long the gloss will last is not known. From the behavior of some paint of this same kind which was seen subsequently, and which will be described later on, it is believed, however, that it is not likely to crack. It is reported that there were comparatively few rust spots on this bridge before repainting, and that the old paint was thoroughly scraped before the new was applied. It was not scraped off, however, as it was found wherever any scraping was done that it was uniformly very tough and adhered well to the metal. The new paint was also tough, and no blistering was seen.

On the east approach girder the web plates under paint were generally found clean, and so were the upper horizontal surfaces of flange angles, although as everywhere else, a few rust spots were encountered. The cover plates on the top of the girders were also found clean.

The top of the cover plates on the end posts had a few rust spots under paint, although not many. Some were also discovered on the inside of these posts, but they were comparatively rare. On the vertical posts, which were built up of plates and angles, the rust spots under paint were the exception. More rust was found here on the lacing and angles than on the plates. The eye-bars were generally clean. The tops of lateral plates on the pedestals were found rusty, but it was also observed on a rainy day that water did not drain off these readily. The webs of floor beams and stringers were comparatively clean, though rust spots were found occasionally. Some spots were also found on the upper horizontal surface of the lower flange angles. The tops of the upper angles of stringers were generally clean under the paint, and the same was true of the floor beams, although these were a little rustier than the stringers.

On the whole, the condition of the metal under the paint on this bridge was quite as good as any examined. The metal seemed to have been rolled smoother than usual, and it was again noticeable that the plates were much cleaner than shapes, and that vertical and covered surfaces were cleaner than those exposed to sun and rain.

Floyd River Bridge.

The Floyd River Bridge was first painted in 1888 in the same manner and with the same material as the Missouri River Bridge, and was repainted in 1894 the same as the large bridge. The external appearance was very good, except that when painting was done, the water in the river was high and the lower parts of the cylinders were left unpainted.

The water has now gone down, and these cylinders looked badly. The paint was about all gone, but there was little rust. Under the paint the webs of girders were usually found clean. There was some rust on the top of flanges, but the clean surfaces predominated.

Sioux City Elevated Railroad.

This structure was painted with a red oxide of iron when erected, in 1890 or about that time, and has probably not been repainted since.

The cylinders carrying the span over the Chicago, Milwaukee and St. Paul Railroad were scraped, and rust was found on them, this apparently originating from the cracks in the scale, which were produced in bending the plates.

The viaduct proper was quite free from external rust. A large number of posts were scraped, and these were almost uniformly found clean under the paint, though not always.

Northern Pacific Railroad Bridge over the Mississippi above St. Anthony's Falls.

This bridge was built in the winter of 1883–84. In the shop the surfaces coming in contact and those inaccessible after erection were painted with red lead, and the entire surface then received a coat of the customary iron oxide paint. After erection it was painted with two more coats of the same iron oxide paint. A fire occurred in 1891 which heated the south span and burnt the paint off to a great extent, after which the entire structure was repainted with the same iron oxide paint originally used.

Numerous spots were found on the cover plates of end posts and top chords, which looked as if hot cinders had dropped on these surfaces. It is possible that these spots may have been started in this way, but they were in each case active rust spots, and subsequent observations elsewhere did not confirm the cinder theory. The spots were not noticed on the other members of the bridge, the paint on them being in good condition.

The metal under the paint on the end posts facing south was more rusty than that on those facing north, being quite clean in the latter case. On the top chord rust spots were found under paint where the plates seemed comparatively smooth. The channels of the vertical posts were usually found clean. There was a little rust, however, on the lattice bars; the eye-bars were comparatively clean. The tops of the stiff lower chords were found somewhat rusty; the sides, however, were generally clean. The webs of floor beams and stringers were usually clean, the upper horizontal surfaces occasionally rusty. A mark painted with white lead on the surface of one of the floor beams surrounding the melt number, and evidently done in the mill, was scraped off, and under this white lead the surface was perfectly clean, while all about it, it was rusty. Similar marks were discovered at Rulo with somewhat similar observations. The white lead thus found was brittle and easily scraped, while the oxide of iron adhered firmly to the metal. Here, again, the plates which appeared perfectly smooth on the surface were usually clean, and the rougher shapes were likely to show rust.

NORTHERN PACIFIC RAILROAD BRIDGE OVER THE MISSISSIPPI BELOW THE FALLS.

This bridge was built in 1885. The specifications called for a coat of oil in the mill. It was painted with iron oxide after erection and repainted with the same paint in 1891. On the west approach some rust spots were found on all members, which resembled the spots on the upper bridge, but inasmuch as they were under the floor the theory that they had been caused originally by cinders does not seem to hold. The general condition of the paint was good. Under the paint the metal was generally found to be clean, with the exception of the top of a pedestal angle, which was quite rusty.

WINONA BRIDGE.

This bridge was given a coat of boiled oil in the shop, and after erection in the summer of 1891, received one coat of red lead and then one coat of white lead. The paint was not well applied, it being put on in daubs, and the metal probably not scraped to any great extent.

There were a few rust spots visible in various places, no one place being worse than any other, and these spots were usually blisters due to the inferior adhesion of the paint to the metal, which was undoubtedly caused by dirt or dampness on the metal when the bridge was painted. One intermediate post on the 360-ft. span was particularly noticeable in this respect, the paint throughout its entire length on the face towards the floor being in bad condition and scaled in many places. In this case there was no rust under blisters, and the presence of machine oil on the metal before painting was indicated.

Where the paint was exposed to sunlight the white lead was considerably cracked, and it is believed that these cracks extended through the red lead, although it was a difficult matter to determine this exactly. These cracks were more numerous where paint was thick than where thin.

In many places moisture had entered between vertical surfaces in contact and run out at the bottom, streaking the iron with rust stains. This was particularly noticeable in the cross-frame attachment to posts and in the upper flanges of floor beams.

While the smoke had blackened the white lead on the cross-frames to some extent, it did not seem to have injured it.

On the cover plate of the top chord there were few rust spots and the paint was not cracked to any extent, although on the sides of the chord the cracking was quite marked. It was true generally that vertical surfaces were cracked more than horizontal ones.

On the lower portion of the drum the paint was in worse condition than elsewhere, it being in scales on the edge of the lower flange and to some extent on its top, almost around the entire circle, and under this scale there was a great deal of rust.

The paint itself was universally brittle, even on the inside of the drum and on the insides of stringers or posts, where neither sun nor moisture could get at it. It was more easily scraped off than on any other bridge previously examined, and flew off on scraping like fine iron scale.

Under the paint the metal was found rusty quite often, and there seemed to be no special rule. On the end posts the metal under the paint was found rusty and clean in spots, and on the top chord, where the paint actually looked better, rust spots were more numerous. On the vertical sides of the upper chord the metal was usually clean, and on the eye-bars almost always so. The vertical posts were quite as likely to be rusty as clean anywhere. On the upper surface of the stiff bottom chords the metal was found rusty oftener than clean. The webs of floor beams and stringers looked well and had few cracks in the paint; there were, however, occasional rust spots. The tops of the stringers were quite clean. The usual rule observed elsewhere, that plates were cleaner than shapes, was not so marked in this bridge; in fact, at times the shapes were cleaner than the plates; neither did the position seem to have affected the amount of rust. A pedestal plate which was scraped was found unusually clean, and a floor beam web on the same pier, rusty.

While rust was quite general, it was not of a dangerous character, being the usual thin yellow film easily scraped off.

Burlington Bridge.

This bridge was given one coat of the usual iron oxide paint in the shop, and after erection, in 1891, it received two coats of the same paint. Not much scraping was done in the field.

The plate girders on the west end showed very little rust, although the paint was faded. On scraping, however, rust was found on all web

plates, with one exception; this one was perfectly clean on one side, and on the other side, exactly opposite the clean place, it was rusty. The plates facing south, and consequently exposed to sunlight, were no worse than those entirely protected from the sun. The upper surfaces of flange angles were comparatively clean; in fact, better than the plates.

On the bridge proper, rust was visible on almost all external surfaces, the end posts, portals and top chords being worse than other places. The surface of the metal in this bridge seemed unusually rough, and the perfectly smooth surfaces quite common elsewhere were practically absent. It looked as if this iron had been quite rusty before being manufactured in the shop, or else there was a great deal of scale on it, or possibly a combination of both.

The top of the north stringer in the south track was in worse condition than any other part of the bridge. Here there was scale almost everywhere between ties, and in many places it is no exaggeration to say that this was ¼ in. thick, and required a chisel to remove it. This condition is explained by the fact that refrigerator cars cast bound drip salt water on the track, and, of course, to the stringer below. The tops of the remaining three lines of stringers were comparatively very clean.

The guard angles were practically devoid of paint and rusty. The north one of the south track was the worst and was covered with scale.

The visible rust spots on the bridge were mostly in the shape of well-developed blisters and of considerable size. It was quite often noticed that under some of these blisters the metal was perfectly clean, the blisters in this case, however, usually cracking in a great many places and indicating that the paint had never adhered to the metal. Probably the surface was covered with machine oil when the paint was first applied, thus preserving the iron but at the same time making it impossible for the paint to stick.

As for the metal under the paint, rust was found pretty generally on cover plates, side plates and angles on the exterior of the end posts. On the inside the metal was cleaner, but rust spots were still readily found. The upper surface of the bottom chord and the outside of intermediate posts and struts all showed more or less rust under the paint. The eye-bars were in much better condition and were usually found clean.

Quite a large number of white mill paint marks were found on this work, and on scraping, clean metal was found under them, while under the other paint the metal was apt to be rusty. The white paint here was brittle and easily scraped off. The iron-clad, on the other hand, adhered very firmly and was very tough.

On the drum, the web plates were surprisingly clean under the paint, the only rust of any extent being found on the north side. As the draw is reversible, this side does not necessarily remain to the north at all times. The flange angles were also in pretty good condition, and the scale found on them at Winona was entirely absent here. On the inside of the drum the struts were usually clean. The web plates of the stringers over the drum were also quite clean, though occasionally a rust spot was found. The cross-frame angles, however, were quite rusty under the paint.

The floor beams and stringers, except on top, were fairly clean, as were also the upper surfaces of the lower flange angles. On the web plate of one floor beam rust was found under the paint in streaks running horizontally, and between these streaks the metal was perfectly clean and bright.

The pimply appearance noticed on the fence at Memphis was quite apparent on this bridge, especially on the top chord. The top chord, so far as examined, was rustier than any other portion of the structure, it having occasional spots 1 ft. square where the paint was all gone. The little eruptions, as at Memphis, were open and active rust centers, and only needed a little time to develop into large spots. The sides of the chords were again comparatively free from rust spots, though they were by no means absent.

Plates in this bridge seemed to be rougher than shapes, and usually there was more rust found under the paint on plates than on shapes. When, however, a perfectly smooth spot was noticed it was quite sure to have perfectly clean metal under the paint. The outlines of old scale could readily be traced on the plates, and under this scale it was almost always rusty. The intermediate posts, made of channels, were more commonly found clean under the paint than rusty. The paint on the tops of the stringers not affected by scale was in pretty good condition, and the metal under it was fairly clean.

The external appearance of this bridge was not as good as that of the Blair Bridge.

The examination as first planned ended here. From the information obtained it was thought best, however, to extend it to a number of structures recently built by Mr. Morison in the vicinity of St. Louis. This was done in January, and, as before, such other structures were examined as could readily be visited. The investigation was further extended subsequently to a number of Chicago structures.

Alton Bridge.

The bridge over the Mississippi at Alton received one coat of iron oxide paint in the shop before shipment, the latter part of 1893, and another coat of the same paint after erection early in 1894. The structure was examined in all sorts of places, and rust was generally found under the paint. The rust, however, was not bad, being mostly of a thin, filmy character, and clean spots were found in juxtaposition to rust spots in almost all places. Rough surfaces usually had more rust under the paint than smooth ones, the latter being clean oftener than otherwise. No special difference was noticed between plates and shapes, except so far as the roughness of the surface indicated. On some angles scale was found, and under this scale was oil with clean metal. Machined surfaces were usually clean; there were, however, some rust spots found on these. Horizontal exposed surfaces were no worse than others. The outside of the drum was probably worse than any other part of the bridge; this was no doubt due to the cracking of the surface scale on plates while bending, and to rusting subsequently.

The guard angles were shipped without painting, and after arrival on the work, were thoroughly cleaned and painted; the metal under the paint was clean almost without exception.

The rust under paint was, as usual, found in spots, and from this it is quite evident that it existed before painting.

The surface of metal around rivets was specially examined, but there seemed to be no difference between the surfaces here and those of places remote from rivets, thus indicating that reaming or drilling had no special influence in this matter.

The bridge, having been so recently painted, presented a good appearance externally, no rust spots whatever showing on the paint.

Bellefontaine Bridge.

The Bellefontaine Bridge over the Missouri River near St. Louis was given one coat of iron oxide paint in the shop before shipment

during 1893, and two more coats of the same paint after erection early in 1894.

The external appearance was excellent, no rust spots of any kind having as yet developed.

Under the paint rust was found in most places; and quite an amount in many of them. In this respect this bridge was quite as bad as that at Burlington; it was manufactured at the same shop. Smooth surfaces were probably better than rougher ones, although this distinction was not as well marked as at other bridges. No special difference was noticed between shapes. Lattice bars and tie plates, or, in other words, small pieces, were found cleaner than larger ones. Cover plates were particularly rusty under paint; the fence was also quite bad. Machined surfaces were usually clean, though by no means always; the rust spots which were found were, however, of a very thin character and usually not large. As at Alton no more rust was observed around rivet heads than elsewhere. The tops of stringers and their cross-frames were usually clean, while the tops of floor beams were not. The webs of stringers and floor beams were in pretty good condition, but rust was found occasionally.

Here, again, the guard angles were received on the work without any paint, and had been carefully cleaned before painting; they were clean almost without exception.

Mill and shop marks painted in white lead were frequently visible through the paint and were examined. White paint was always brittle. Under mill marks the metal was always clean, while under shop marks, though generally clean, rust was found occasionally.

The resident engineer reports that not much scraping was done, as the metal looked well when it came with a coat of paint on. Had he suspected the actual condition he would have scraped the whole structure. The same is reported by the resident engineers of the other shop-painted bridges.

The viaduct, while showing rust in spots, as all other bridges have done, was much cleaner on an average than the bridge. This was not manufactured in the same shop as the bridge proper.

Merchants' Bridge.

The Merchants' Bridge over the Mississippi at St. Louis received one coat of iron oxide paint in the shop before shipment in 1890, and two coats of the same paint after erection in 1890.

A great many rust spots were developing in various places, without any very great regularity, over the entire structure, the east main span being probably worse than any others. The rust was usually in small spots; there were some posts, however, as well as some eye-bars, which had very large scales throughout their entire length. These indicated plainly that no care was taken in cleaning the metal originally. The end posts were better than some of the intermediate posts. The floor system was generally in excellent condition except the tops of floor beams in the east span, which were badly scaled. The bridge needed repainting, and when this is done it should be thoroughly scraped.

Under the paint rust was found in many places as usual, but clean metal seemed to predominate. The paint adhered very firmly to the metal where there were no visible rust spots, and was exceedingly tenacious. No difference was observed as to the rust spots under paint on account of location or exposure, and very little on account of shapes of material. Whenever the metal was smooth it was likely to be clean, as had been noticed on all structures. Here, again, no more rust was noticed near rivet heads than elsewhere. Machined surfaces were rusty under paint as well as others. The indications were, however, that this rust was present before painting, as in no case was there a rust spot visible on the exterior of paint on machined surfaces.

Eye-bars were possibly in a little better condition, with some exceptions, than other members.

Many mill marks originally painted with white lead were seen on this bridge and scraped, and the material under them was always clean. The paint used, presumably white lead from its color, was always brittle and came off very easily, leaving the mark plainly cut out in the bright metal against a background of iron-clad paint, which failed to come off on scraping a surface somewhat greater than the mill mark.

It was evident that the badly rusted members had not been cleaned properly in the shops. In one or two cases clay or soil was actually found under the paint, indicating that the metal had been lying on the ground, and in other places it was quite evident that machine oil had not been cleaned off.

St. Louis Elevated Railroad.

The elevated railroad was examined along the levee from the foot of Franklin Avenue until it turns west, and in a few places where it was

accessible west of the levee. This structure was oiled in the shops, and after erection in 1890, was given two coats of patent iron oxide paint of different colors, the first coat looking very much like red lead. The paint was not in specially good condition; rust spots had begun to show in a great many places on the posts and stringer webs. These spots were generally very small, but indicated pitting, inasmuch as they were in the shape of open paint blisters. In some places these blisters were very numerous and hardly a post or girder was free from them. Under the paint the iron was as usual rusty in spots, and no regularity was observed as to exposure or shape of metal. Generally the rust under paint, where it had not worked through, was only in thin films; some places, however, were found which were quite badly rusted. It is said that special pains had been taken to clean this metal after erection, inasmuch as it had been lying on the levee very long and had become very rusty before erection. The paint was not specially tough and came off rather easily; in some places it was even brittle.

Some distance from the levee, but east of Twelfth Street, the viaduct was in process of extension. The new work was oiled in the shops before shipment. Through the oil the character of surface was plainly visible; while it was no doubt as clean as the average of new work, there were, nevertheless, many rust spots on the metal, there being no place 6 ins. square where there was not some kind of a rust spot. This new work was being painted with a mixture of litharge and charcoal ground in oil, made specially for the company after its receipt. This paint is said to have given excellent satisfaction in the tunnel, where it has been in use for five years, and where it has proved superior to any other. Not much attention was being paid to scraping the metal before painting.

Twelfth Street Viaduct, St. Louis.

This viaduct was quite old and was about to be taken down and replaced by a new structure. In passing under it, it was observed to be exceedingly rusty everywhere and some of the posts to such an extent that the metal, where originally in contact, had spread on account of rust developing on both surfaces, and had forced off the heads of the small rivets. These posts were generally covered with scale from $\frac{1}{8}$ to $\frac{1}{4}$ in. thick. One or two of them were scraped somewhat, and a few paint spots were found. The structure had evidently been painted a good

many times with paint of various colors, the one next to the metal being a dark brown, indicating iron oxide. Wherever a paint spot was found remaining, the metal under it was found clean, but unfortunately very few spots of paint were found on the structure. This structure had been standing over 20 years, and the fact that the metal was still clean under a few paint spots indicated plainly that the paint, even though it had been iron oxide, protected the metal, and that had the entire surface been clean when paint was first applied, no doubt it would still be in fair condition.

Union Passenger Station, St. Louis.

In passing along the street on the east side of the Union Passenger Station, and, therefore, in a position where the metal could not be reached for purposes of scraping, but where at the same time it was not exposed to any extent to the smoke of engines, it was noticed that the general appearance was good. One post was discovered, however, which had large scales of rust on it throughout its entire length. H. P. Taussig, M. Am. Soc. C. E., Chief Engineer, informed the author that this structure was painted with red lead in the shops in 1891, and after erection, in 1892, was painted with two coats of red lead mixed with lampblack. Mr. Taussig was not satisfied with red lead, inasmuch as he applied the best he could get to the bases of the columns and afterwards concreted around them, and found that in six months the paint was entirely gone.

Mound Street Viaduct, St. Louis.

This structure was erected in 1890 and received two coats of iron oxide paint. It was beginning to show some rust spots at various places, but these were not bad. Under the paint the usual condition of clean and rusty iron was found, the clean predominating. The paint was very tenacious and adhered firmly to the iron.

St. Louis, Kansas and Northwestern Round House.

The roof girders of the round house, which were erected in 1893, were painted in the shop with a carbon primer paint, and after erection received another coat of the same paint. The paint was still in a soft condition, and was, therefore, easily scraped off. Under the paint, however, the metal was perfectly clean, even directly over the stacks of the engines.

Rush Street Bridge, Chicago.

This is the first highway bridge over the Chicago River from its mouth. It was built in 1884, and was apparently originally painted with an oxide of iron paint. It was repainted in 1892 with a light colored paint, reported by the men in charge as being lead and oil.

The condition of the paint was good, there being very few rust spots visible. The paint itself was brittle wherever scraped, and under it numerous rust spots were found. As usual, the rust was in spots, and perfectly clean metal was found about as often as rust. Some of the rust spots were quite bad, but they had not come through the paint.

State Street Bridge, Chicago.

The State Street Bridge was built in 1887, and was first painted with red lead and subsequently with a light colored paint, presumably white lead tinted. It was repainted in 1892 with paint of the same color as the Rush Street Bridge, which paint was apparently of a poor quality, as some of it had washed off and was badly cracked. The condition of the paint as a whole was good, however, very few rust spots being visible.

On scraping, the paint was found quite brittle, although the red lead seemed to adhere better than the paint on the Rush Street Bridge. Rust spots were again found under the red lead, although the metal usually was clean.

The drum and floor were evidently painted with an iron oxide paint, which was wearing quite as well as the paint on the trusses. On the drum two mill marks were discovered, which were well covered with paint, while the surface immediately adjoining was decidedly rusty. Apparently in the first painting these marks were not covered, and the metal around them left free from paint, which is not an unusual practice. The metal in these unpainted spots evidently rusted before final painting, and the rust had eaten through the paint, inasmuch as the drum in other places was in fairly good condition. These mill marks upon being scraped showed perfectly clean iron under the white lead. Other parts of the drum, where the oxide of iron paint was still in good condition, were equally clean. The floor was badly rusted; it was inaccessible for scraping.

Dearborn Street Bridge, Chicago.

The draw bridge over the river on this street was built in 1872, and served for many years at Wells Street. It was moved to its present site in 1888. It had evidently been painted with some form of oxide of iron paint originally, and had not been repainted frequently, as the paint was very thin, the last coat being probably applied in 1888 and being of the standard kind used by the city at that time, viz., an iron oxide mixed with oil according to the city formula. The external condition, however, was good, and, on scraping the metal under the paint, it was found remarkably clean, very few rust spots indeed being found. The paint was fairly tough and adhered pretty well to the iron.

Dearborn Street Viaduct, Chicago.

The bridge over the Chicago and Northwestern Railroad tracks was built in 1888. It was painted with a patent iron oxide paint and had not been repainted since. There were many rust spots visible on the trusses; the floor was not examined. The paint was tougher than that on the other bridges along the river in this neighborhood, and the metal under it was generally clean, although rust spots were found in places as usual.

Clark Street Bridge, Chicago.

This bridge was erected in 1889. It was painted in the shops with red lead, and after erection with the city's standard iron oxide paint.

The trusses showed considerable rust everywhere, especially on top of upper chords and near the floor where the paint is subject to abrasion. The floor beams, approach girders and the members under the floor in general were in much worse condition, specially the approach girders, where the webs were decidedly rusty. The horizontal surfaces, both on top of the top chord and on the under side of girders, were much worse than vertical surfaces.

This bridge, though built one year later than the bridge on Dearborn Street over the tracks of the Chicago and Northwestern Railroad, was much rustier, and the paint was very much more brittle and did not adhere as well to the iron.

Wells Street Bridge, Chicago.

This bridge was built in 1888, and was painted the same as the Clark Street Bridge.

The trusses were in much the same condition as at Clark Street, though perhaps a little better. There was no class of members free from rust, although some were worse than others, and some classes of surfaces were in worse condition than others. Here, again, horizontal surfaces, as, for instance, the top chord, the top of girders transferring the weight to the drum, the top of the drum, and the under horizontal surfaces of floor beams, stringers and plate girders, were very rusty.

The webs of the girders transferring weight to the drum, the webs of the drum, and the webs of the approach girders, however, showed very few rust spots.

The paint was almost without exception brittle and very easily scraped off.

Where no rust spots were visible, the metal under the paint was comparatively clean, although thin, filmy rust spots were discovered on most of the members that were examined.

It may be stated that in all of the Chicago bridges the floors were practically inaccessible, and were examined only from a distance. They were all in worse condition than the upper work, which is readily explained by the passage of numerous tugs under them producing vast volumes of sulphurous smoke, which, it is well known, is one of the worst enemies of paint.

Lake Street Bridge, Chicago.

This bridge was built in 1886, and is said to have been painted with one coat of red lead in the shop and subsequently with patent oxide of iron paint; there was, however, no indication of red lead anywhere. It had evidently been repainted. The visible condition of the paint was fair, there being many rust spots visible. The paint was quite brittle, and under it were the usual rust spots.

Lake Street Viaduct, Chicago.

This is immediately west of the draw and was built in 1886. It was evidently painted with iron oxide paint. The condition of the paint was good, and on scraping was found fairly tough and generally adhered well; the iron under the paint was clean, as a general thing, although rust was again found in spots as elsewhere. The character of the rust found under the paint was generally the same as heretofore encountered, viz., a bright yellow, which did not seem to be particularly active.

Lake Street Elevated Railroad, Chicago.

Some of the posts on the Lake Street Elevated Railroad were scraped and examined. Although this structure was only one year old, and the paint was perfectly fresh, the iron under the paint showed the usual spots of rust scattered over clean surfaces.

Madison Street Bridge, Chicago.

The draw bridge over the river was built in 1891, and the specifications called for one coat of red lead and oil before leaving the shop. The first coat, however, was not red, but of a greenish gray color. The later coats were to be metallic paint; they were black and thin. The structure showed some rust spots on the trusses and a great deal of rust on the turn-table. The paint was uniformly very brittle, easily removed, and the metal under the paint was generally rusty, although clean spots were found occasionally. The rust, wherever discovered, was very decided, even where it did not show through the paint. The condition of this bridge under the paint, where no rust spots were visible on the exterior, was worse than any of the other bridges on the Chicago River visited up to that time.

The metal for this bridge had been manufactured for some time before it could be erected, owing to delays in building the substructure. During this delay it was stored in the contractor's yard under a shed.

Madison Street Viaduct, Chicago.

The viaduct over the Chicago, Milwaukee and St. Paul Railroad, immediately north of the Union Station, was built in 1891; it was painted next to the iron with a greenish gray paint of the same color as the draw-bridge and with a black paint over this; the bridge had developed a large number of rust spots. The paint was very brittle, and under it the usual rust spots and clean metal were found, rust spots being quite as frequent as clean metal.

Jones & Laughlins' Bolt Shed, Chicago.

In 1884 Jones & Laughlins, corner Lake and Canal Streets, having occasion to put a temporary addition on their building for the storage of bolts, made it a wooden frame covered with corrugated iron. This corrugated iron has now been in place for over 10 years. It was first painted in the mill with a pure oxide of iron mixed with pure

linseed oil, and had been repainted several times since. The exterior showed no pits indicating previous rust, and on scraping the metal was found perfectly clean. On the interior of the building the corrugated iron is exposed and had never been painted since erection; here considerable rust had been developed. The roof was reported as being perfectly tight, and the external conditions as good as the sides.

The method pursued in first painting this corrugated iron is to use a paint composed of pure oxide of iron, made by simply grinding a hematite ore, and pure linseed oil, and applying this immediately after the iron has left the corrugating rolls, it being found that any delay in painting is detrimental to the wearing qualities of any paint. It is believed that the surface of the iron absorbs oxidizing agents immediately after the original scale is broken, which make themselves felt even after paint is put on. It is the experience of the above firm that oxide of iron paint is superior to all others.

Adams Street Bridge, Chicago.

The draw bridge was built in 1889, and the first coat of paint was red lead, with subsequent coats of gray and white, presumably mixtures of lead paints. All the paint was quite brittle and easily scraped off, and under it the metal was fairly clean, but rust spots were discovered on all members.

Adams Street Viaduct, Chicago.

The viaduct over the railroad tracks at the Union Passenger Station was built in 1885. It was originally painted with an oxide of iron paint, and apparently with a carbon paint subsequently. This latter was practically gone, and the original paint was comparatively thin. Under it the iron was unusually clean, although some rust spots were discovered. The paint was brittle in some places and tough in others.

Jackson Street Bridge, Chicago.

The draw was built in 1888; the first coat of paint was apparently red lead, supplemented subsequently by oxide of iron paints. The visible condition of the paint was fairly good, but it was very brittle. Under the paint numerous rust spots were discovered, but most of the iron was clean.

Jackson Street Viaduct, Chicago.

The viaduct over the railroad tracks was built in 1888, and it was apparently painted with an oxide of iron paint. The visible condition of the paint was fair, it adhered fairly well, and was not very brittle, neither could it be said to be tough. The metal under the paint was generally clean.

Metropolitan Elevated Railroad, Chicago.

The rolling bascule bridge over the Chicago River was incomplete at the time of the examination. It had received one coat of so-called red lead, which had very little lead in it, but there was a good coat of oil. Under this paint the usual rust spots were found scattered over the otherwise generally clean surfaces.

The spans crossing the railroad tracks immediately west of the river were erected during the winter, and were first painted with an oxide of iron paint, and subsequently received a coat of zinc and lead mixed. The oxide of iron adhered well to the iron and was fairly tough, although it was not old enough to show what it will do.

Van Buren Street Lift Bridge, Chicago.

This bridge was also erected during the winter, and had just been opened to traffic. It was first painted with red lead, and had subsequently been thoroughly painted with oxide of iron. On scraping this structure, after penetrating the surface, the red lead was found to be exceedingly brittle, and while the metal was usually clean, many rust spots were found.

Harrison Street Bridge, Chicago.

The draw bridge was built in 1877, and had been painted apparently exclusively with iron oxide paints. The posts are of the form known as the American Bridge Company's columns. The shapes entering into this were comparatively rough, and under the paint on these posts the metal was usually rusty. On the bars near the turn-buckles the metal was generally clean, while at some distance from them rust was more common. The external condition was good.

Harrison Street Viaduct, Chicago.

The viaduct over the railroad tracks was built in 1881. It was painted with an oxide of iron paint next to the iron, on top of which

there was a light color, presumably white lead, and the surface was again oxide of iron. The bridge showed some rust spots, but not many. With the exception of the first coat, the paint was quite brittle; the first coat, however, adhered well to the iron. The metal under the paint was comparatively clean, but showed rust in various places.

Wisconsin Central Bridge at Polk Street, Chicago.

This bridge was erected in 1889. Some of the members were evidently painted first with red lead and others with oxide of iron; subsequently the structure was painted black, probably with some carbon paint. The bridge was very rusty in all its parts. The oxide of iron adhered to the metal much better than the red lead and was tougher. Where rust had not already penetrated the paints, the metal under the paint was generally clean.

Polk Street Draw, Chicago.

This structure is a rather primitive affair, consisting of a pair of box girders tapering from the center towards the ends and supported by a system of hog chains. It was built in 1872. The structure had evidently been painted with iron oxide paint only, it being all one color. This paint was in good condition, very few rust spots showing, and under the paint the surface of the metal was very clean.

Polk Street Viaduct, Chicago.

This structure was built in 1887. The first coat of paint was apparently of oxide of iron; subsequently it was painted with a light color, presumably white lead, and on top of this oxide of iron. The external appearance of the paint was good, the upper coats were quite brittle, the first coat adhering well to the iron. In most places the metal under the paint was found to be clean.

Taylor Street Bridge, Chicago.

This structure consists of an approach which runs from Polk Street, parallel to the Wisconsin Central track, to Taylor Street, thence west to the river, and is composed of iron bents and plate girders erected in the fall of 1894, and a draw bridge across the river, built in 1872, originally used at Adams Street, and moved to Taylor Street in 1889.

The old draw was originally painted with a brown paint, evidently a mineral paint, and had not been repainted very often since, as the paint was very thin and practically of the same color throughout. The external appearance was very good, there being very few rust spots. Under the iron some rust spots were found, but as a general thing the metal was very clean. In places where rust spots had developed and broken through the original paint, a subsequent coat had covered them thoroughly. The paint was rather tenacious, and adhered to the iron fairly well.

The first coat of paint on the new viaduct at the east end of the draw-bridge was specified to be red lead, though analysis proved it to be mainly iron oxides; the subsequent coats were of iron oxide. The external appearance of the structure was good, no rust spots being noticed in any place except on the railing. Pains were taken to examine some of the girders immediately over the main tracks, and these were found without any rust spots. The same was true of the girders along the Baltimore and Ohio freight depot, between Polk and Taylor Streets. These girders are continually exposed to smoke from engines passing under them.

On scraping, a few spots were found where the red paint adhered exceedingly well; generally, however, there was little difficulty in getting through the surface, and when once the scraper had reached the bright iron under the red paint, it was an easy matter to scrape the paint off clean, it being very brittle. The paint had not been on long enough to display the mill marks; one of them was, however, accidentally discovered, and this, as usual, scraped off easily. Immediately adjoining this mill mark the red paint adhered better than in any other place, and was, perhaps, the only place where it could be called satisfactory.

Under the paint rust spots were found as usual, clean metal predominating.

Taylor Street Viaduct, Chicago.

This viaduct carries Taylor Street over the Pennsylvania and Chicago, Burlington and Quincy Railroads. It was oiled in the shop, and after erection in 1891 was painted with the city's standard oxide of iron paint. The paint was very thin and brittle, and the structure was very badly rusted. Wherever no rust spots showed through the paint, the metal was usually clean under it.

The posts supporting the main span of this viaduct were painted with P and B paint. This paint was very thin, did not adhere well to the iron, was not cohesive in itself, and when scraped it came off very readily in the shape of powder. The metal under this paint was generally clean, but it would evidently stand no abrasion whatever, the paint rubbing off with very little effort.

On the girders constituting the approach to this bridge the paint was scaling off, and a large portion was already gone. The exposed metal was very rusty in most places. There were many places, however, where the iron was still very bright, showing that the oil originally put on was still protecting it. These bright spots had undoubtedly been exposed for less time than the others. Wherever the paint was still intact, it could be scraped off very readily, exposing bright, clean metal.

Lassig Bridge and Iron Works.

A visit was made to the shops of the above company to observe the condition of metal after manufacture into structural work and before painting. This company houses all metal immediately on its receipt, and it does not leave cover until after it is painted, except possibly in summer, when the weather is suitable.

A number of plate girders were finished and being given a coat of linseed oil. Notwithstanding that the metal had been housed, there were many rust spots on the web plates, and also some on the angles. The latter were covered with scale. The metal was being cleaned by means of putty knives and whisk brooms before oiling. Steel brushes were also used. If there is anything unusual in this method of cleaning at shops, it is perhaps on the side of thoroughness. After cleaning, the plates still showed thin, yellow rust spots, and these showed plainly, but of a darker color, after the oil was applied.

The oil was scraped from some rust spots under oil on dry girders which were in the yard, and the yellow color so often found was developed.

Members of a bridge built by this firm some six years ago, which bridge had met with an accident, were in the shop for repairs. These had been first painted with the patent iron oxide paint noticed on the Sioux City Bridge and repainted in 1893. Practically no rust spots were to be seen, and it was very difficult to scrape off the paint on account of its toughness and adhesive qualities.

Some metal was examined which had been lying in the storage room for a year. This was entirely covered with rust, even though exposed to neither sun nor rain.

The following bridges mentioned in the foregoing pages, viz., Cairo, Memphis, Merchants' at St. Louis, Bellefontaine, Leavenworth, Rulo, Nebraska City, Plattsmouth, Union Pacific Railway Bridge at Omaha, Blair Crossing, Sioux City, Alton, Burlington and both of those at Minneapolis, were painted with a pure iron oxide known in the trade as Cleveland iron-clad paint, brown purple, No. 3. It was generally bought dry, and mixed with pure boiled linseed oil on the work. The chemical composition of the pigment, according to an analysis reported by the manufacturers, and to an independent analysis made by R. W. Hunt & Company for the author, is as follows:

	Manufacturer's Analysis. Per cent.	R. W. Hunt & Co.'s Analysis. Per cent.
Sesquioxide of iron	93.68	92.40
Silica	3.20	3.36
Alumina	3.06	1.69
Lime	....	0.84
Organic and volatile	....	0.85
Magnesia	....	0.48
Sulphur	Trace.	0.029
Loss	0.06	0.351
	100.00	100.00

It is a selected natural iron ore simply ground fine.

The painting itself was done by men employed by the day under the direction of the resident engineer. For this work painters were avoided, as it was found that intelligent laboring men were more to be relied on for thoroughly scraping and covering the metal.

The patent paint mentioned was all from one manufacturer, although it might be of different brands. It was, however, an iron oxide paint, the pigment in one brand being composed of about 33% of iron oxide and 60% of silica, calcium sulphate and calcium carbonate mixed, as determined by three analyses from the same number. These analyses varied widely, however, in the relative proportions of the latter ingredients, and the wearing qualities of the paint as observed by one large consumer were by no means uniform, paints furnished at first being better than those furnished more recently, and a paint from a

different manufacturer containing more oxide of iron has now been substituted by this consumer.

The city of Chicago has painted its bridges for a number of years with a paint specially prepared after its own formula, the pigment being an iron oxide of substantially the same analysis as that first given above. Pure boiled oil is specified.

From the foregoing observations it will be noted that rust was found to a greater or less extent on all structures examined, regardless of location of structure, of member in structure, or of surface of member. It will be further noted that this rust occurred practically always in spots, or, in other words, that clean metal could readily be found adjoining a rust spot, if the scraping was carried far enough. In most of the structures examined the larger part of the metal under the paint was found clean.

The character of the rust spots thus found under the paint seemed to be wholly independent of the time the structure had been in service. Most of it was simply the thin yellow film easily brushed off and evidently doing no harm, as it was found no worse in bridges 12 and 23 years old than in those one year old. In some cases deeper rust was found, but this was at least as frequent in the newer bridges as in older ones, and, in fact, it is believed rather more frequent. The Blair Crossing Bridge, built in 1883, was much cleaner under the paint than the Bellefontaine Bridge, built in 1893, and the Dearborn Street draw is much cleaner than that at Madison Street.

It would seem from the above that it was not unreasonable to conclude that pure iron oxide used as a pigment in paint is not a cause of rust on metallic structures exposed to air. This question was the chief occasion for making the investigation, and, to the mind of the author at least, the question is satisfactorily settled, notwithstanding the theory advanced by many to the contrary. Furthermore, wherever paint had been applied to clean metal, the metal had evidently been protected so long as the paint lasted, no matter what the paint was, as was shown on some of the Chicago bridges, notably the Taylor Street Viaduct.

As for the lasting qualities of different paints it is to be regretted that the variety examined was not greater, that the exact composition of those found was often unknown, and that the red lead had in no instance been in service over seven years.

It has been justly said that a paint as a preserver should have good covering power, should be neutral to the metal to which it is applied, tough, should adhere well to the metal, and be durable.

As the paints examined consisted almost wholly of iron oxides and leads, these alone will be discussed at length.

The covering power of iron oxide has not been questioned so far as the author knows. On the other hand it is generally admitted that red lead, which has recently been preferred, spreads very poorly and that it is, therefore, difficult to get it applied properly. Red lead is said to combine chemically with oil, and to form a soap which sets in a comparatively short time. The mixture or compound must be applied before the setting takes place, or it is of little value. The theory of chemical combination is quite commonly accepted and is supposed to be the valuable feature of this class of paints. Some authorities in the matter say, however, that there is little chemical affinity and object to any such affinity, preferring a pure mixture with linseed oil to any chemical combination.

Linseed oil, so far as known, is the best liquid within reasonable cost that can be used for paints, and is, in fact, the preserving agent of the paint. It is, however, readily destroyed by weather, and to preserve it a pigment is mixed with it. The more inert this pigment is to the oil, and the more stable in itself, the better. Iron oxide is inert with oil, and, so far as made from natural ores, it is one of the most stable pigments known.

The worst enemy of paint is water, and this attacks the oil. The porosity attributed to oxide of iron paints by many is the porosity of the oil, and not of the mixture or pigment. Experiments were made by C. B. Dudley, M. Am. Soc. C. E., to illustrate this. He found that while linseed oil alone, after being dried, absorbed water rapidly, this absorption decreased the greater the amount of iron oxide present, and practically ceased finally.

Paints forming chemical combinations are more liable to deterioration, the oil having already been attacked.

Many of the paint soaps formed by a combination of pigment and oil, while insoluble in water, are nevertheless not durable.

The neutrality of paint to the metal has already been mentioned so far as pure iron oxide is concerned. Oxides made from copperas or other sulphur processes are not considered here. Lead paints are un-

doubtedly neutral, as is shown by the numerous white lead mill marks which were scraped, and under all of which the metal was perfectly clean.

As for toughness and adhesive qualities, iron oxide has again been said to be brittle and easily removed, while lead paints are claimed to be the opposite. The investigation has pointed to exactly the opposite conclusion. Where pure oxide of iron with pure oil was used, the paint without exception was tough, and, where dry, adhered firmly to the metal, it being practically impossible to scrape it off. In the case of the Plattsmouth Bridge, where some of the paint came off easily, it was in tough leathery strips, and this was due to imperfect drying quite as much as to anything else.

On the other hand, but a single case was found where lead paint adhered well or was tough. In this one case the red lead did both. The numerous mill and shop marks examined were without exception more brittle than the oxide of iron paint around them. It has been questioned whether the red lead and white lead examined as such were really what they looked like. No chemical analysis was made and the authority for its genuineness is only the specifications, the integrity of the contractors, and the color of the pigment. If, however, it is impossible to buy an honest article of a specified kind, the endeavor to get it had better be abandoned for something one can be sure of, and which is better than the inferior article purchased under a high-sounding and high-priced name.

It is possible, and in fact probable, that much of the observed brittleness was due to adulteration of the oil by means of turpentine or benzine, or other petroleum products. The latter are known to be positively injurious to paint, causing scaling or want of adhesion, while the former is at best only inactive except as a diluting agent, and dilution is in itself objectionable. Lead paints being more difficult to spread than the iron oxide, the tendency to use diluting agents with them is much increased. A case may be cited where a painter was engaged to apply pure red lead and oil, and abandoned the work because the paint was too difficult to spread and the use of turpentine was not allowed.

As for durability, the case of the Blair Bridge may be cited as one illustrating that of pure oxide of iron mixed with pure oil. This bridge has now stood nearly 11 years since the second and last coat

of paint was applied, and it is in very fair condition to-day, in fact much better than some of the newer ones. Furthermore, where rust has not actually eaten through the paint, the latter is good for some years yet. A still older bridge, that at Bismarck, N. D., might be cited, this having been erected in 1882, painted in 1883 with the same oxide as the Blair Bridge, and not since, and it is reported in good condition still. This bridge was not, however, visited in connection with this examination.

The durability of paint is evidently largely dependent on climate. The Bismarck Bridge is in a high latitude, and the paint has lasted many years. The Memphis Bridge is pretty well south, and rust has developed much more rapidly.

There is no structure in the list examined that has been painted with red lead which can be compared with the Blair Bridge, either for age or general conditions. The Winona Bridge is only about four years old, and while at present its appearance is better than that at Blair, the condition of the paint is much worse and there are many scales and blisters which will soon come through. In this connection it may be noted that it is claimed that red lead will not blister, the contrary of which, however, is decidedly in evidence at Winona. As the paint here was bought dry and mixed with oil as used, the conditions should be reasonably favorable to red lead. It is believed, however, that blistering is quite independent of the paint.

Comparing the Dearborn Street Viaduct with the Clark Street Bridge in Chicago, the evidence is somewhat in favor of the former. Comparing the old Dearborn Street draw and Taylor Street draw with the Clark Street and Wells Street Bridges, the first two show to decidedly better advantage. In both the above comparisons the iron oxide comes out ahead. This may, perhaps, be accounted for from the fact that these Chicago bridges are constantly exposed to the sulphurous fumes from coal smoke. White lead is more rapidly decomposed by sulphurous acids than any other paint, and red lead is not far behind, while iron oxides are affected very little.

In old New England barns painted with Venetian red and white trimmings, the white lead wears off the trimmings entirely long before the red iron is much affected.

Furthermore, the lead compounds are always artificial combinations, while iron oxides can be obtained in abundance from Nature without any preparation except grinding.

The trainshed of the St. Louis Union Station painted with red lead throughout is already scaling.

Only two cases of carbon paints were observed, and these were not old enough to show their qualities. Neither, however, were tough nor adhered specially well to the metal, though both protected the metal.

It is hoped that something interesting may be brought out in regard to these paints in the discussion.

The lasting qualities of paints colored with lampblack are well known. Old signs, where the white lead ground color has been gone for years, still have perfect letters in black.

Many asphalt paints have been on the market, but some of them contain absolutely neither asphalt nor other carbons; and others, instead of being true asphalts, are coal tar mixtures. It is claimed for true asphalts that, unlike petroleum compounds, their oils are non-volatile, and that once properly applied, they last practically forever.

But after all that has been said about paints for preserving metallic structures, it is necessary to look first to the condition of the metal to be preserved.

It will be clear from the observations given in detail in the first part of this paper that the rust which exists under the paint is not a thing which has developed on account of imperfect covering qualities of the paint, but has been there from the day the paint was first put on. In the majority of cases this rust is doing no harm under good paint, and the owners of a bridge need not feel that they must remove all old paint, because the structure is rusty in spots under it. In repainting a structure it should be thoroughly scraped and brushed with steel brushes; but where old paint adheres thoroughly to metal, it is a good foundation to build on, and it should be the aim to get the rust spots equally well covered.

Too little attention has been paid to cleaning the metal before the first coat of paint has been put on, and usually the metal has been painted as quickly as possible to cover up the spots.

It is well known that plates are rolled with smoother surfaces or with less scale than shapes. After rolling, the material lies out of doors for a time, both at the mill and bridge shops, for various reasons, before being manufactured into structures. Plates lying on top of each other form a covering for themselves, while shapes are not so well

adapted to this. Moreover, plates, being smoother than shapes, are less susceptible to the influences of weather. While thus exposed, no doubt the formation of most of the rust is begun, and there is nothing to prevent its development until the material is assembled into a member and finished. It is then generally pushed out of doors and painted.

It should be cleaned and scraped, but from the author's observation this is done superficially, if at all, and in some shops only when the inspector is at hand to see it done. Many inspectors are not aware of the importance of proper cleaning, and are satisfied when metal is entirely covered.

It is one of the most difficult things for an inspector to obtain good cleaning of metal at a shop, even if the management is inclined to have it properly done. He can rarely devote much time to the painting, and, as a result, the men intrusted with that work get the rust out of sight with the least possible effort by simply covering it up with paint. If the rust so covered up has not begun to pit the iron, the chances are it will never do any harm; but if it is already well developed and of some thickness, it will have enough oxidizing agents in its pores to develop more oxide, swell up, crack the paint, and the continuation is obvious. In such a case the paint is usually condemned as unsatisfactory, when it is probably not at fault at all.

The first requisite, therefore, in the direction of preserving iron structures is to insist on absolute cleanness of metal before any paint is applied.

Probably the best way of securing such a condition would be to clean the metal from scale immediately on leaving the rolls and coat it then. The uniformly clean metal under mill marks points strongly to such a proceeding. If linseed oil were used for this purpose, the pieces could easily be immersed whole at a very small cost.

This would undoubtedly add a little to the first cost of the metal, but such additional cost would be saved in the final painting, if not sooner. Undoubtedly some of the preservative coating would be burned off in riveting, but this would be little, and these spots, together with the new rivets, could be covered immediately after riveting. Forged members which are annealed could be coated to best advantage after annealing.

If this plan is impractical, the cleaning could best be done in the

shop after manufacture, either by rotary steel brushes operated by power, by the sand blast, or by pickling. The portable drill might be developed for the first process. If metal were treated in some such way as above indicated and cleaned perfectly, the question of a proper and durable paint would lose much of its importance. There ought to be no reason why such results should not be accomplished.

The manufacturer would, of course, expect to be paid for the extra work, but the result would well justify the cost.

Under present conditions it is necessary to get the best cleaning in the shops that can be exacted. It is the opinion of the author that the best thing to apply there is a coat of pure linseed oil. Boiled oil has been preferred in the past, because it dries more rapidly than raw oil, but if a little time can be given the latter to dry, it is, no doubt, better, as it will penetrate more readily the minute surface cracks and any little remaining rust, and is less likely to be adulterated than boiled oil.

With a coat of oil nothing is invisibly covered up, and if scraping and cleaning are not properly done, it will be apparent,

After erecting metal so treated, the engineer in charge can readily see how much scraping is necessary and can have it done before paint is applied. When paint has been applied in the shop it usually looks well when erected and gets no scraping; additional coats are put on. The whole does not always wear well, and when it does not, the paint is called poor.

Some criticism has been made against using oil as a first coat, the objection being that pigment cannot get next to the metal. As long, however, as the oil is the principal preservative ingredient in paint, this objection does not seem a good one. Paint certainly adheres as well when applied over oil as when applied directly to metal, and lasts as long. The Blair Bridge may be again cited as an illustration.

That metal is likely to be cleaner if oiled in the shop than if painted may be illustrated by the Leavenworth, Nebraska City, Omaha, Blair, Sioux City and Cairo Bridges, as against the Alton, Bellefontaine, Burlington and Merchants' Bridges. The former had quite clean metal under the paint, the latter very rusty metal; the adhesion was good in all.

Care should be taken to have surfaces to be painted free from dampness, and that new paint does not freeze. Many an otherwise good

job of painting has been spoiled by applying paint in rainy or freezing weather.

If metal has been properly cleaned and paint properly applied, there need be no fear that any paint, composed of pure oil with a good pigment, will not protect the metal so long as the paint lasts.

The selection of a paint becomes a question of durability under conditions which at present scarcely exist.

The present investigation fails to point to red lead as the one pigment above all others for painting iron structures exposed to air, but rather that it should be avoided.

Iron oxide is far preferable, as the author sees the matter, aside from the question of cost, and in cost the advantage is certainly with it.

DISCUSSION.

C. B. Dudley, M. Am. Soc. C. E.—From the standpoint of the chemist, the speaker was unable to say, after 8 or 10 years of careful study, that he knew of anything that can be applied to an iron structure which will absolutely prevent corrosion. No one apparently knows, beyond question, what makes iron corrode when exposed without covering; there are a number of theories, and a good many experiments have been made. If three things are kept away from iron it will never corrode. These three things are moisture, oxygen and carbonic acid, but it is problematical if any one of the three being absent, corrosion or rusting would not take place, although it is pretty positively known that water alone, without free oxygen and without carbonic acid, will not corrode bright surfaces for months. It is said that if moisture and gases can be kept away from the surfaces, they will not corrode. The inference is that paint will keep those things out, but unfortunately it does not, and that is the key to the situation. He knew of no paint which will exclude, after it is dry, moisture and gases from the surface coated with it. Linseed oil alone, spread on a surface and dry, is about like a sponge. Take a piece of glass, coat it with oil and allow it to dry a month; then look at the piece of glass under a microscope, and pretty satisfactory proof will be seen. If a microscope is not available, put a drop of water on the surface and cover it up so that it will not evaporate. Dry linseed oil, such as has been subjected to a moderately dry atmosphere for a month, when treated with a drop of water on the surface will look on the next morning much like a shriveled apple. It will lift up from the surface and will dry down again

Mr. Dudley.

Mr. Dudley. if the water evaporates. Linseed oil alone is not a substance which keeps out moisture and gases, but when mixed with pigment it keeps them out better. Take one glass and coat it with linseed oil; on the next glass put 5% of pigment of any sort that does not have a chemical action with the oil; on the next one put 10 parts of pigment and 90 parts of oil, and so on until the mixture is too thick to spread. It will be found that with an increase of the pigment the action is less with the drop of water. The pigment apparently fills the pores which are produced when the linseed oil dries, in a measure, and helps to keep out the gases and moisture. Linseed oil, when it dries, is no longer an oil, and it has undergone a chemical change; chemists call it linoxyn. It is fairly demonstrable that two or three things have taken place during the drying; first, there has been an absorption of oxygen; second, there is very little doubt but there is an elimination from the oil during the process of drying, of carbonic acid and perhaps water vapor. Those two substances passing out of this thin layer of liquid leave little apertures; they must have apertures to come out. If pigment is mixed with the oil apparently the apertures are less large, or are partly filled up. The best paint to prevent corrosion is a mixture of linseed oil and lampblack, but this paint dries too slowly. To overcome the difficulty of exceedingly slow drying, the lampblack may be mixed with any inert substance, yellow ochre, oxide of iron or possibly red lead (although the last may cause a chemical change in the oil) retaining as much lampblack as is possible and still get satisfactory drying.

Mr. Emery. Charles E. Emery, M. Am. Soc. C. E.—Iron ships are peculiarly liable to corrosion, being subject to alternate states of moisture and dryness under the influence of salt water and salt air, all independent of galvanic action, which cannot be entirely prevented. The methods adopted for preserving iron ships have, to a large extent, become well settled. They consist of untiring vigilance and the free use of good paint. New paints, so-called preservatives, anti-rusting and anti-fouling compositions have been tried, but red lead is most depended upon. He had been instructed by one of the Government departments some 10 or 12 years ago to make an examination of one of the earliest iron vessels constructed in this country, being informed preliminarily that there was very little money with which to make repairs. The vessel was built before 1861 and before angle irons were in vogue. The frames were of bar iron bent edgewise and the plates fastened on by clamps extending over the bars and riveted down each side. The vessel was very lightly constructed originally and of light draught for use in shallow waters; after the civil war it had been fitted as a revenue cutter and at the time of the examination was laid up at Mobile, Ala. The officers had reported that masses of rust 2 ins. or more thick had been removed from the plating inside the hull, and considered the

vessel must be in a dangerous condition. It appeared on examination that there were masses of what appeared to be rust ½ in. to 2 ins. thick, which in many cases had to be broken off with chisels, bars and hammers and would finally show a rusted surface on the interior plates of the vessel. Some of this scale adhered so persistently that the impression was created that the chisel must go through the bottom of the vessel, but sound iron was in all cases found underneath it. The phenomenon was due to the way the vessel was cared for. The men were supposed to scrape the iron clean and paint it periodically. Some interior parts were inaccessible, others difficult of access, and there was some neglect in the scraping so that the paint at some points frequently went on over previous collections of rust. Moreover in some parts of the ship, cleanliness was promoted by whitewashing, which was entirely removed by the scraping, so that the mass taken off was a conglomerate, colored throughout with rust, but representing very little weight of iron. At many points, particularly near the frames, no corrosion had apparently taken place, and the scraping showed paint to all appearance like that applied originally. The greatest corrosion appeared to occur where the original coating had been in some way broken. Mr. Emery.

The speaker had the vessel put on a dry dock and the bottom hammered from stem to stern. The plating was originally very light, and where no corrosion had taken place it did not appear to be more than $\frac{5}{16}$ in. thick, and in the 25 or more years of service this had become reduced at points to a mere shell through which it would have been easy to drive a hammer. It was found, however, that there was much metal left of nearly the full thickness, the thin spots were generally not of large area, and by cutting holes it was found that many of them still contained ¼ in. of good metal. The bottom was so much of a springboard that it was difficult to cut a hole with a chisel from below and he persuaded a number of the officers and men to try it, with the result that all had very much respect for the old vessel when the examination was completed. On account of his instructions he decided simply to patch over those places on the hull which sounded light and in which any part of the area was less than $\frac{1}{16}$ in. thick. Although a considerable number of patches were required, still the surface covered was a very small proportion of the whole bottom. The officers ran the vessel several years more without further repairs, when she was ordered North, all her woodwork was stripped off, the iron hull thoroughly cleaned, the thinnest points broken through, and the vessel rebuilt as a composite vessel by placing on it an outer skin of yellow pine plank bolted in most places to the old plating and occasionally through washers hooked over the frames, the heads being let into the wood and cogged with wooden plugs dipped in white lead. It was only found necessary to remove about a dozen of the old frames in making this

Mr. Emery. reconstruction, though here and there where the frames had become thin angle iron was placed against them. The vessel is still running.

He drew the conclusion that it was impossible for an iron structure to be wholly destroyed by corrosion when any attempt had been made to care for the same. He supposed that the rust was principally due to the carbonic acid in the atmosphere, which is absorbed by any moisture present and finally an active corrosive solution is formed. A surplus of water would dilute the solution and check the action, and the drying of the plates would also check it, but the recurrence of moisture would cause a repetition of the phenomena and further corrosion. It appears, therefore, that the covering up even of rust had some beneficial effect, as it prevented further action, though parts that were actually well cleaned and then thoroughly covered were better protected. The masses of rust which collect on bridges do not represent any large quantity of iron removed. The oxide is of very much greater bulk than the iron itself and may be removed by thorough scraping, and the surface covered so as to stop further injury. He thought, however, that the experience with the old ship showed that even if some little rust is left it may be so thoroughly covered up as to do no further injury. He considered that circulation of air had considerable to do with the rapidity of the corrosion. In the smaller enclosed places of the old vessel the destructive action was not so great as in the central and more open spaces, although the latter were more accessible and received better attention. A cement covering doubtless acts on this principle so long as it is kept either dry or wet, but not alternately dry and wet.

Attention was called to a paper by the speaker in which it was shown that the return pipes of an underground steam system corrode very rapidly while the steam pipes remain intact, the apparent reason being that the carbonic acid which is absorbed by the soil acts most virulently at or a little above the temperature of steam at atmospheric pressure.*

Mr. Morison. George S. Morison, President Am. Soc. C. E.—There is one feature of this paper which seems to have been left out in this discussion, much as it deserves attention. A great deal has been said of the use of different pigments and of their durability, but the question of how the iron is to be put into proper condition to receive the pigment is the most important thing of all. The author suggests that it be cleaned with steel brushes, by the sand blast, or possibly by pickling. William Metcalf, Past President Am. Soc. C. E., considers that it is a hazardous thing to pickle iron and steel, that there is danger that the effect of the pickling will never be removed. It is absolutely necessary, in order to secure permanent effects from a pigment, that the

*See paper on "District Steam Systems," in the *Transactions* of the American Society of Civil Engineers, Vol. xxiv, p. 192.

paint should come directly on the bright surface of the metallic iron. Mr. Morison.
It is a common thing to note the durability of mill marks, which are usually put on with a poor quality of white lead; the reason of that durability is that they are put on very soon after the metal has left the rolls. It may be necessary to paint the metal for important structures before it goes out from under the roof of the rolling mill. This is the principal requirement; the painting of the metal must not be deferred until it has begun to deteriorate, and that is the question iron manufacturers should take in hand and discuss; the best method of accomplishing this result, the best method of getting the pigment on the metal with least expense, at the earliest possible moment.

George A. Just, M. Am. Soc. C. E.—The subject is one which Mr. Just.
does not permit correct conclusions to be drawn from the observations or experience of any one person, both because of the difficulty of ascertaining the exact facts and conditions of each case examined, and the extreme length of time needed to develop the absolute value of any particular method. Even the paper seemed to the speaker to show this, and it is only by the collation of the experiences of the many that it will be possible to decide upon a method which will prove an advance on present practice. For this reason, the paper has a distinct value in adding data to the present meager knowledge on the subject. A proper solution of the question would be a marked step in advance, for not only must metal structures exposed to the weather receive attention, but also those skeleton frames which have in late years played such an important part in the rebuilding of the larger cities, and are ordinarily assumed to be fully protected by their encasing material. In many cases, however, the protection afforded is but slight, since one of the objects of building in this manner is to secure the use of walls of less than usual thickness. In many cases the columns and girders of these frames are surrounded by no more than 4 ins. of brickwork, an entirely insufficient protection against the weather. This condition of affairs has helped to raise the question of the life of such structures, of the relative rate of corrosion in cast-iron, wrought iron and steel, and of methods of protection which should prove effective. For a solution the investor has turned first to his architect, and then to the engineer, who, however, has also been unable to shed much light on the subject.

At present no better practicable method of protection is known than a good paint well applied. The engineer has, then, to decide what is good painting and what constitutes a good paint. Patent paints and compounds which may have had but a limited use cannot come in for consideration, nor can such processes as the Bower-Barff, the use of which has become confined almost entirely to interior iron-work, in which cases, even, it has not proved an absolute rust protector, since the coating will scale, especially if applied to the finer grain of wrought iron as compared with cast-iron.

Mr Just. To secure painting of good quality, as the author has pointed out, a clean and rustless surface is first required. This applies equally well to subsequent coats, as to primers. The vehicle used should be the best, which is generally agreed to be pure linseed oil. The pigment should be neutral, producing no chemical or galvanic action, and as finally divided a substance as is obtainable, in order to mix well with the oil and to fill as completely as possible the pores of the oil formed in drying. The conditions of the weather at the time of application and the care of the laborer will also affect the final result.

Those who have observed the deterioration of painted surfaces of metallic structures will have noted that a rustless surface is a first requisite. The rust spot will swell and burst, either from the self-contained moisture, or from that reaching it through the paint skin. An inspection of the various lines of elevated railroads extending through New York shows this very clearly. Take the supporting columns at any cross street, such as Forty-second, and it will be found that the Second Avenue line with Phœnix columns is generally in a good condition. The paint blisters raised by rust are small and few, and rust is generally found along the edges formed by riveting the flanges of the sections together. The Third Avenue line, having channel-latticed columns, the webs of the channels running north and south, is generally in a fair condition. The iron is still well covered inside and out, but the paint blisters are larger and more plentiful. Other rust is found principally for a distance equal to the height of trucks from the ground, where the traffic scratches and destroys the paint skin. The Sixth Avenue line with closed sections of channels and plates, the plates running north and south, is in a bad condition. Many large broken blisters are found, especially on the webs, and the paint and rust scale are readily removed in large flakes. The cover plates are in comparatively better condition than the webs of the channels, but rust is found along the riveted edges and around the rivet heads, as in the Second Avenue line. The Ninth Avenue line with channel-latticed columns on the down track is fair or rather better than on Third Avenue, while on the up track the open columns built of four 6-in. extra heavy I-beams are in a worse, but hardly bad, condition. This up track is the oldest existing line. The paint blisters on the columns of this line are few and small, and large pieces are not readily found or removed. As on other lines, rust appears in streaks to the height of covered trucks. These lines afford, perhaps, as good an opportunity as can be found anywhere for testing the merits of painting on metallic structures, both because of their unfavorable surroundings, and because of their age; the Third Avenue line, for instance, was built in 1878.

The chief engineer of the Manhattan Railway Company, Mr. J. Waterhouse, stated that the last coat was applied to these roads, from

Forty-second Street northward, in the case of the Sixth Avenue line, in June, 1889; on the Ninth Avenue line in October, 1889; on the Second Avenue line in October, 1890, and on Third Avenue line in May, 1893. From this it appears that the condition of the roads is not altogether indicative of the age of the paint, excepting only that the one in the worst condition is the one that had not been repainted for the longest period. The character of earlier coatings, the location of the various roads and the shapes or sections which form the columns, have probably all affected the result. Mr. Just.

The paint used in each of these cases was mixed according to the company's standard formulas, viz.:

FORMULAS FOR MIXING 50 GALLS. OF OLIVE-DRAB STRUCTURE PAINT, MANHATTAN STANDARD.

	Summer formula.	Winter formula.
White lead, "Jewett's"	300 lbs.	275 lbs.
Bergenport zinc, strictly best quality	175 "	150 "
French ochre, " " "	100 "	90 "
Prussian blue, " " "	1 lb.	1 lb.
(The above pigments to be ground in Campbell & Thayer's raw linseed oil, and the weights given include that of the oil.)		
Lampblack, strictly best quality	½ "	½ "
Boiled linseed oil, Campbell & Thayer	8 galls.	9 galls.
Raw " " " "	15 "	15 "
Spirits turpentine, strictly best quality	3 "	3 "
Liquid drier	2 "	3 "

Mr. Waterhouse further stated that they preferred a lead paint, and that their manner of testing the many mixtures offered the company is to simply paint thin metal sheets with the same, and to expose them under one of their overhead bridges, by the side of sheets painted with their own standard. So far they have found nothing to give them better results than the mixture they have adopted. They like a light colored paint also because the rust streaks assist them in locating loose rivets.

While, as the author points out, it is generally accepted that the quality and life of a priming coat is dependent to a very great extent upon the care exercised in removing mill scale, rust and grease, it is equally well agreed that with present shop methods, even when demanded by the specifications, this is done but superficially if at all. And this will always be so, until the method specified requires such shops, labor and tools, as to form in each case an appreciable element of cost which the manufacturers must recognize as clearly as punching or other labor, and hence include when making their prices for work.

Better results would be achieved in this direction if engineers in charge of important new work were to specify that the material shall go directly from the rolls to an adjoining closed shop or cleaning shed, where the scale is to be removed by light portable power-driven wire

Mr. Just. brushes or other suitable means, and the pieces are at once to be immersed in a bath of pure linseed oil. Then they are to be sent to riveting or other shops when dry enough to handle, and when the work is complete, they are to be sent to an enclosed paint shop, where a good coat of paint of a kind approved or specified by the engineer is to be given before shipment, ample time being allowed for drying. This process could not be objected to on the ground of the economy of the present method, but would be attacked because of the loss of time in getting material into the field, but it is perhaps the only means by which an improvement can be achieved.

Present practice is pretty well confined to the use of iron, lead and graphite or similar carbon paints; which one of these will give the best results can be determined only from wide experience. As to cost and capacity, these paints can be rated about as follows:

	Cost per gallon.	Covering capacity of 1 gall. Square feet.	Cost of paint per 100 sq. ft.
Oxide of iron (Prince's)	$0 53	600 to 700	9 to 7⅞ cts.
Red lead (National Lead Company)	1 25	500 to 700	25 to 18 "
Superior graphite (Detroit Graphite Manufacturing Company	1 10	600 to 800	18 to 14 "

The graphite paints have had no very extended use for bridges or skeleton frames of buildings, but the rivalry between iron and lead paints is of long standing. It is conceded that the latter sets rather too quickly, and runs too readily when applied to vertical surfaces. It is poisonous, and, as the iron paint makers claim, destroys the oil and forms a coat of iron oxide beneath the skin. The lead paint makers, on the other hand, claim that iron paint is in itself a rust producer, and that it scales and blisters more readily than red lead. The lead paint, however, seems to be growing more into favor with engineers.

It is well to bear in mind what part of the cost the dry pigment or the oil bears to the total cost of painting. In the case of iron oxide the cost of pigment forms about two-tenths, and the vehicle (linseed oil) eight-tenths of the cost of the paint. In the case of red lead paint the cost of the pigment bears about three-quarters and the vehicle one-quarter of the cost of the paint. The mixed paint forms but one-third to one-half the entire cost of painting. The labor, in ordinary bridge painting, without scraping, had been placed at twice the cost of the paint.

In the figures given, the cost per gallon was derived by taking in the case of Prince's "Mineral," 6¼ lbs. of mineral at 1½ cents, and 6¼ lbs. of raw linseed oil at 52 cents per gallon (7½ lbs. to the gallon), and in the case of red lead, 18 lbs., at 5 cents, and 5 lbs. of oil at 52 cents per gallon. The graphite paint is sold ready mixed, per gallon, at the price given.

CORRESPONDENCE.

Mr. Gayler.

CARL GAYLER, M. Am. Soc. C. E.—The paper will increase the attention paid to existing structures, and its suggestions in regard to scraping and painting at the mills and shops will probably have a lasting influence on future practice. The writer wishes to add to these suggestions that the repainting of bridges should always be done by day labor, never by contract. Work like this, where every square foot of surface has to be treated with equal care, can only be done satisfactorily by men who have no interest in slighting it, viz., by men employed by the day and working under the directions of the engineer or a competent foreman, preferably, of course, by the regularly employed repair force of the company or municipality, as the case may be. Every engineer who has had painting done knows how difficult it is to make a painter do proper cleaning and scraping before covering the surface with the paint.

The remarks in regard to the Twelfth Street Viaduct in St. Louis are not correct. The posts have not failed "on account of rust developing on both surfaces of the metal, where originally in contact, and forcing off the heads of the small rivets," but because they were (for the last of them are now replaced) 6-in. octagon Keystone columns with only ¼-in. thickness of metal, and ½-in. rivets spaced 12 ins. apart. Under the greatly increased traffic, since the viaduct was built, the joints in the columns opened and rust formed between the flanges in consequence. The viaduct was furthermore not condemned on account of the condition of the iron work, but a new one was deemed desirable with a wider roadway and easier grades. The principal objection to the present structure, however, was the danger from derailments, as not less than four different times during the last ten years have columns been knocked out from under it.

Mr. Artingstall.

SAMUEL G. ARTINGSTALL, M. Am. Soc. C. E.—The requirements for paint on bridges and viaducts in a large city are, no doubt, more severe than for those in almost any other location. The usual condition of the atmosphere in a large city is such as to be extremely detrimental to paint on outside iron work. Moreover, the conditions under which the work must be painted are not often conducive to good results. It is difficult to keep the work clean while the painting is in progress, and the painting must often be done in unfavorable weather, or occasion much delay in the work.

Draw bridges are usually placed at an elevation sufficient to give headroom for the passage of tugs and other low-decked craft, and the viaducts form crossings over the railroads. In either case the structure is frequently enveloped in clouds of gas and vapor. That portion of the structure below the floor line receives this combined gas and vapor, with an amount of fine cinders which is blown against it with con-

Mr. Artingstall.

siderable force and in a heated state. This action appears to be much worse in the case of viaducts than in that of draw bridges, due probably on the one hand to the custom of tugs of dropping their stacks and shutting off the draft when passing under a bridge, and on the other hand to locomotives standing under viaducts and to the nearness of the top of the stacks to the viaducts in many cases. Chicago has yet to find a paint which can withstand this action with any degree of satisfaction. Tests were made with various paints furnished the city by manufacturers, and while some showed much better lasting qualities than others, none could withstand this action for any considerable length of time. Of all tested, red lead paint and a certain graphite paint showed the best results. At present the city is trying the method of forming a ceiling on the under side of the structure of 1-in. dressed and matched boards. This method promises very well, and aside from the first cost may prove a cheap and permanent protection for the floor systems of the viaducts.

For a number of years the city has, with some exceptions, used the following specification for the painting of both bridges and viaducts: First coat, to be put on in the shops, pure red lead and pure boiled linseed oil; second and third coats, to be put on after erection, oxide of iron and boiled linseed oil, in the proportion of about 8 lbs. of the oxide to the gallon of oil. In some instances the priming coat was pure boiled linseed oil only, and in others a metallic paint. However, after trying many substitutes for the above specification, it has been returned to in each case as giving the best results under all conditions.

While agreeing with the author as to the prime importance of a clean metal on which to paint, and the necessity of a good quality of oil whatever the pigment to be used, the writer does not think the investigation has been an entirely impartial one. It is not a difficult matter to collect data to prove the superiority of almost any reasonably good paint. Such a thing has often been done by manufacturers. A great amount of data and any amount of testimony could readily be collected to prove the superiority of red lead as a paint for iron work.

The writer's experience with paints and his tests of them tend to disprove some of the conclusions reached in this paper. He has not found the oxide of iron paint to withstand the action of gases and vapors from locomotives better than red lead, but the reverse. While agreeing that of the cases cited the iron oxide paint was usually tougher than the red lead paint, he does not think the oxide paint was otherwise in as good condition. He finds that the oxide paint is much more liable to pit and scale than the red lead. In several bridges examined recently which were painted with iron oxide, he found them badly pitted and scaled. His reasons for using the oxide paint for the

last two coats and for field painting generally are not because of a belief in the superiority of this paint, but because of the inconveniences connected with the use of red lead paint for this work, and of the difference in the cost of the two paints. Mr. Artingstall.

R. Montfort, M. Am. Soc. C. E.—While the writer fully concurs with the author that sufficient attention is rarely given to the removal of rust prior to the application of paint in bridge shops, his experience as to the lasting and protecting qualities of paint composed of pure red lead and linseed oil compared with iron oxide and linseed oil paints is in favor of the red lead. Mr. Montfort.

For ten years prior to 1883 the Louisville and Nashville Railroad Company painted all of its iron bridges with red lead; the average time when it became necessary to repaint was from seven to eight years. In 1883, for economic reasons, it was decided to abandon the use of red lead and substitute iron oxide, which was much cheaper. As a result, it was found necessary to repaint bridges every four years, on an average. There were cases in which great care had been taken in the original painting and in repainting, where the iron oxide lasted for seven years. On the other hand, in exposed locations along the Gulf Coast, it was necessary to repaint bridges three years after their erection. They had received one coat of linseed oil at the bridge shops before being shipped, and two coats of oxide of iron paint in the field. In 1891 red lead was again adopted as standard.

A serious objection to the application of oil prior to shipment is that iron so coated is very apt to become covered with small particles of cinders in transit, which stick to the oil and form a rough surface beneath the two coats of paint subsequently applied in the field after erection.

A mixture of red lead and oil when applied alone is objected to on account of its color corresponding with the customary danger signal; it also has the objection that it fades and gradually becomes white. To overcome these objections, 1 oz. of lampblack to 1 lb. of red lead is added to the last coat, which produces a dark chocolate color.

On old bridges that were painted once or oftener with red lead, and afterwards repainted with oxide of iron paint, the red lead appears to adhere well to the iron, and can readily be examined by scraping off the iron oxide paint; it can also be seen in many places where the iron oxide paint has worn through and rubbed off.

The writer never found any structure suffering seriously from rust beneath the paint that did not show rust through the paint. In old structures all rust should, of course, be removed as far as possible with steel brushes before repainting. It appears that steel is more liable to rust than iron. The results obtained from any kind of paint depend to a very large extent on the character of oil with which it is mixed and the care with which it is applied.

Mr. Howe. W. B. W. Howe, M. Am. Soc. C. E.—The adaptability of any particular paint for the preservation of iron exposed to the weather is not likely to be determined by the examination of structures treated with it, unless complete information is at hand concerning the condition of the surfaces when painted and the ingredients of which the paint is composed, as well as their freedom from injurious adulterants.

The experience of the author, as far as it relates to the use of red lead, is so at variance with the writer's that the latter feels there must have been something wrong with the red lead, either in the pigment itself or in the method of applying it. The value of red lead as a paint for iron structures has been established the world over by both careful experiment and actual use. He has found it the best paint for the primary coat. It is an expensive paint and is frequently adulterated with substances that are themselves injurious to iron, and the difficulty of applying it properly probably leads to the work being done imperfectly at times. He has yet to learn of an instance of failure of pure red lead properly applied. He has used it largely in priming galvanized iron and with greater success than attained with any other paint.

Mr. Wilson. Joseph M. Wilson, M. Am. Soc. C. E.—The paper is a valuable one in that it contains reports of actual results from the use of the various paints in question, extending over a period for several years, and no amount of theory can equal practical experience. The writer has made use of red oxide of iron paint in his practice for 35 years with very satisfactory results, especially for girder bridges and other work that for æsthetic reasons was not required to be painted in light-colored finishing paints. On one prominent railway line this paint was used exclusively for all bridges, and his attention has never been drawn to any bad results from its employment. It is possible that there are, as with all paints, material differences in the quality of various brands, depending on the mode of manufacture and adulterations or in the methods of application, and the same is true for red lead. He does not think that the case has been proved against red lead so as to justify those who have been in the habit of using it in giving it up. But few cases of red lead appear to have been examined, and there is not the certainty in these that the material used was of first quality that obtains in most of the cases of iron oxide. Both materials are, in his opinion, good, although cheapness and ease of application are undoubtedly in favor of the iron paint. Of course everything depends upon the proper quality of the material, and with red lead there is more chance of deception in this respect and more inclination to add improper ingredients, for the purpose of increasing the facility of application, than there would be with iron paint. He has, however, seen iron oxide that after a few years will rub off like whitewash.

In his experience he made use of red lead for priming as long ago

as 1860. The first iron bridges built by the Pennsylvania Railroad Company were on the Pittsburgh Division in the original construction of this road, and had a priming coat of a tar paint (composition unknown), which after some years of service (probably 15 or 20 years) was found under the other paint, which had worn off, in excellent condition. Mr. Wilson.

He considers it of prime importance that the material should be protected with raw linseed oil, even before manufacture, especially if standing exposed to the weather, and that a coat of the same be put on after manufacture, and thoroughly worked into all joints and openings, the iron being previously scraped clean from all scale. The oil should be put on when the temperature is not lower than 60° Fahr.

A. E. Hunt, M. Am. Soc. C. E.—The writer agrees with the general position taken, that oxide of iron is the best paint for metal structures, if pure oxide of iron is used as the pigment of the paint and if enough is used to give good coloring matter to the rest of the pigment. Calcium sulphate is a material largely and to the best advantage used with oxide of iron, in at least equal proportions with the oxide of iron. Very many good paints are made with only 35% oxide of iron. He would suggest a minimum of 35% oxide of iron in the paint. A small percentage of calcium carbonate is advantageously added to neutralize the acid there may be in oxide of iron paint, but the proportion should not be over 5%, nor indeed should any other similar substance be used in large quantities, that will decompose by weathering. Mr. Hunt.

His experience is that much of the rusting under and flaking off of iron paints has been occasioned by the very poor quality of the paint used in the past. Much of it has contained free acids, which caused corrosion of the iron under the paint, due to the influence of this acid in the pigment, and much of the flaking off of the paint has been occasioned by the decomposition of the salts, such as carbonate of lime, in the pigment of the paint. Calcium carbonate in the shape of powdered limestone is a cheap substance to use in paints, and in some paints of inferior quality large quantities of it are used. Such paint he has found to be very poor and to last but little time without decomposition. A considerable amount of adulteration of linseed oil has been made in the past by means of turpentine or petroleum products, such as benzine, and these additions have always been to the detriment of the oil. Pure linseed is without doubt the best oil to be used for painting structural iron work.

G. H. Thomson, M. Am. Soc. C. E.—A corrollary from an ancient law referable to matter and its conditions reads: "Fire is a destroyer of conditions," and is applicable, in the prevention of rust, in the preparation of iron and steel prior to painting. Rust is a hydrated oxide of iron. Paint over rusted iron, and oxidation still continues under the paint. If fire is applied to the rusted metal, so that all Mr. Thomson.

Mr. Thomson. the water is driven out of the rust, and the metal then painted, the rusted iron will not oxidize further.

Old bridges badly rusted can be cleaned by this method. The rust can be loosened by kerosene oil, and the application of the torch will burn out all the kerosene oil as well as change the yellow (hydrated) oxide of iron to the red (anhydrous) oxide. In using the torch for cleaning old bridges, the writer has found it to be slow and therefore expensive, but effective. Eye-bars when removed from the annealing furnace can be painted as soon as cold, instead of leaving them on the ground for weeks to absorb moisture, resulting in incipient rust.

The preparation of metallic bridge work for painting is worthy of much consideration for future work. The expense stands in the way. If the old-fashioned method of pickling is adopted, tanks of long dimensions will be required. If the iron be cleaned by hand torches, the expense is one of labor, or time, alone. A scheme for shop fire cleaning by gas jets will reduce the labor of torch cleaning, but its cost is problematical. The expense of either method will not find much to encourage its adoption by railroad managers at present.

Mr. Randolph. L. S. Randolph, M. Am. Soc. C. E.—In painting locomotive tanks considerable trouble is caused by rust forming under the painted and varnished surfaces. There was a tradition among the painters that a rust spot having been once formed, it could never be eradicated sufficiently to prevent its continuing to form rust, even after it had been painted over. The writer's observations satisfied him that the rust spots could be very readily cleaned so that there was no danger of further trouble from each individual spot. The idea of their being ineradicable probably arose from the minute cracks which formed in the painted surface, admitting moisture which was formed by condensation on the surface of the tank. The service required from a paint on the tank of a locomotive is probably more severe than that required of a bridge paint, notwithstanding the greater care which can be taken in painting the tank.

In regard to the relative durability of lead and iron paints, the writer's observations coincide with those of the author in that the iron paints are far more durable than lead paints when exposed to the weather. The action of the iron oxide seems to be to protect the leather formed by the linseed oil from the weather. Following up this idea, it has seemed to the writer that a paint used for this purpose would give most excellent results if sanded, as is frequently done with the external woodwork on houses.

Iron paint is the easiest to obtain pure. It is too cheap, as a rule, to be adulterated to any very great extent, and as the linseed oil is the most important part, it can be purchased in the paste form, the oil being bought separately. A little practice will make anyone quite expert in detecting adulterations in linseed oil. The writer has found that the

presence of iridescent bubbles on the surface of the oil, when shaken, almost invariably indicates the presence of either resin oil or a petroleum product, which are the most dangerous adulterations likely to occur. Of six samples of white lead bought several years ago, only one deserved the name of white lead, as it alone contained lead hydroxide. Mr. Randolph.

A. S. Riffle, M. Am. Soc. C. E.—The author's investigations bring out some interesting and decidedly important facts. Doubtless every engineer engaged in structural iron work has his own decided opinions regarding iron preservatives, strengthened, perhaps, by years of experience. The test conditions, however, are so varied that a consensus of opinion is scarcely to be expected. The author has struck the keynote in stating that the condition of the metal before the application of the primary coat is even more important than the quality of the paint. The writer's experience during several years' engagement as engineer of bridges on the western division of a transcontinental line, during which time he personally supervised the construction of many new structures and the repairs of a few old ones, confirms the conclusions of the paper in many particulars. During his connection with this road, the iron for a few of the bridges was oiled before leaving the shop, and in these cases it was found to be in exceptionally fine condition, never requiring the use of the wire brush, which was usually the case with iron which had been painted. Paint covers a multitude of defects, and corrosion is one of these. The writer has always advocated the use of oxide of iron in preference to lead paint, not because the latter was without merit, but because the former possessed more nearly those qualities which are required of a metal preservative. In stating his preference for oxide of iron paint, he does not wish to be understood as accepting as desirable every mixture masquerading in the market under the pseudonym of "durable paint," for these are scarcely less numerous than the structures they cover. An iron paint prepared from carefully roasted iron ore is certainly more likely to be free from injurious elements than one which has not been so treated, since by this process carbon dioxide is expelled and oxygen absorbed, thus precluding any possibility of further change by exposure to atmospheric or chemical action. When properly ground it mixes well with oil, a great advantage over lead, which cakes so readily that a uniform distribution is almost impossible. A paint to fulfill the many requirements, must possess many certain and reliable qualities. It must be elastic, yielding readily to the expansion and contraction of the metal ; must not blister, scale or crack ; must contain no injurious chemicals, and at the same time be non-absorptive to rain and moisture ; must adhere tenaciously to metal under various atmospheric conditions ; in fact, must have an almost unlimited number of virtues and no faults. No Mr. Riffle.

Mr. Riffle. doubt every engineer is thoroughly sincere in his advocacy of his particular kind of paint, but a pigment that has shown excellent qualities in one place might be utterly worthless in another.

Several years ago the writer was engaged to make an examination of bridges on various roads in a South American republic, an English syndicate having acquired them by lease a few years before. An examination found the bridges on two of these lines in a most deplorable condition, although they had been painted frequently since their construction 20 years ago. On one line a bridge consisting of 27 iron Pratt trusses, each of about 80 ft. span, was almost destroyed by corrosion. The end suspension rods, 1 in. square and one per truss, were in a majority of cases reduced in cross-section by corrosion fully one-half, in some cases even more. There was scarcely a member in the 27 spans that was not seriously impaired beyond the limit of safety. Another bridge of 4 spans, each of about 100 ft., was in about the same condition. On another line a 200-ft. through Fink truss, built by the old Baltimore Bridge Company, was found to be similarly affected. In several places the main diagonal bars, running from the center panel to the end posts, were almost perforated. These bars were about 1 x 5 ins. and no difficulty was experienced in picking holes over $\frac{1}{2}$ in. in depth in many places with an ordinary pocket knife blade. These bridges had been painted frequently, but with what kind of paint the writer did not at the time ascertain. These bridges were exposed to particularly trying atmospheric conditions. Owing to their peculiar location they were at times exposed to heavy, protracted fogs, then again to the intense heat from a tropical sun, and at all times to the salt breezes of the Pacific. On another line an examination of 17 iron bridges found them all in excellent condition, although some of them had not been painted since erection, nearly 20 years before. However, on this road the atmospheric conditions were such as to render corrosion to any great extent impossible. Rain was almost unknown, and the temperature of the atmosphere scarcely varied more than 25° or 30° during the year. The remains of the old Verrugas Viaduct on the Callao, Lima and Oroya Railroad in Peru, which the writer replaced with a cantilever bridge for L. L. Buck, M. Am. Soc. C. E., its chief engineer, was found to be singularly free from corrosion excepting pins and bolts, although it had not been painted since its erection in 1871 by Mr. Buck.

These illustrations serve to show that paints giving excellent results in one locality would be wholly inadequate in another. The paint which stands the test under the most severe and varied conditions is certainly the best. In closing, the writer must say that he is scarcely prepared to condemn lead paint for iron structures, having used it but little; but from his experience with oxide of iron, he has no hesitancy in continuing its use, believing it vastly superior to any other paint in the market.

A. F. Robinson, M. Am. Soc. C. E.—From a careful reading of the paper, the writer has arrived at the following conclusions as to the protecting power of the paint in the cases noted by the author: *First*, of the 34 structures painted with oxide of iron, 48% rank as good, 29% as medium and 22% as poor. *Second*, of the eight structures painted with lead, 71% are good and 29% are medium, while none are poor, notwithstanding the fact that in case of the Winona Bridge the paint was not properly applied. Mr. Robinson.

White lead, as used for marking iron at the shops, is ground in oil, but it is thinned with turpentine or benzine before use. The large proportion of drier thus added would be apt to make the paint brittle and easy to rub off, as has been mentioned in the paper in several places.

In 1884 the writer did the inspecting for some 75-ft. through plate girders that were erected in Kansas. The iron received one coat of paint (Williamsport, No. 31) at the shop and one after erection, and has been painted perhaps once since then. Before receiving the first coat the iron was thoroughly cleaned with steel wire brushes, all spots of hard scale being oiled and scraped before painting. This work was erected during July and August, and no painting was done in damp weather. At present writing all the horizontal members are quite badly rusted on both sides, the spots or blotches showing in much the same manner as described by the author.

A railway viaduct just east of Kansas City, over two other railway tracks, was built in 1887 or 1888 and had two coats of common iron oxide paint. When examined last September, this structure was very rusty, there being almost no signs of paint left, and the rust appearing in large patches all over the work.

During the past season the writer examined some iron bridges in Mexico near the Gulf Coast, where the atmosphere is full of moisture at all times. In the dry season a very heavy dew falls almost nightly, and this covers the iron work with moisture. Part of the bridges were painted with "Cleveland iron-clad" paint at the shops and some with other iron oxide paints; they were all repainted three or four years ago, but without scraping or brushing. When examined, this paint was soft and spongy and could be very easily scraped off. Under the paint the iron was quite rusty, though the rust spots did not always seem to be active. In some of these structures the paint had turned very black on the surface, and under this coating it did not seem to be soft or spongy as above. On structures farther from the coast and at higher altitudes, where the air holds but little moisture, the iron oxide paint was doing better, though the pimples and blisters with rust spots underneath, were quite common.

In the 75-ft. through girders above noted, the iron was as clean as it could be made without some special treatment, such as oiling at the

Mr. Robinson. rolling mills or pickling, and still the paint (iron oxide) did not protect the iron properly. In the other special cases mentioned, the iron oxide also failed to a greater or less degree.

A lot of rails which had been painted with red lead were taken out of the foundation for a proposed building at the site of the Woman's Temple, Chicago, Ill. The writer was informed these rails had been laid for seven years, but the iron was still bright and fresh under the paint.

Lead is seldom properly mixed for the first or priming coat at the shops, and it is not always used while freshly mixed. Lead paint requires much more rubbing or brush work than iron oxides, and the want of this may be one cause for the rust spots appearing.

Last year the writer had charge of the painting of a 150 ft. span which had received a coat of oil at the shops. Red lead paint was used and 1 gall. covered an average of 930 sq. ft. in first coat and almost 1 200 sq. ft. of surface in second coat. The paint was mixed fresh and 33 lbs. of lead were used for each gallon of oil. The writer has never been able to obtain an iron oxide paint that covered more than from 500 to 900 sq. ft. of surface per gallon. Lead paint properly mixed and applied may not protect iron work completely, but it seems to the writer that it can hardly do worse than the iron oxides.

Mr. Nichols. O. F. Nichols, M. Am. Soc. C. E.—It is true that oxidation and decay are certainties of existence which may be checked but cannot be prevented. On reading the paper one is astounded that the best bridges are so poorly protected after so many generations of painters have died firm in the faith that metal structures can be protected from such rapid oxidation. There are many things not understood about oxidation as well as about paint. Why, for instance, should steel oxidize less rapidly and differently from iron, and why should light iron, as thin sheets, band iron and steam pipe oxidize more rapidly than other forms?

If incipient oxidation did not set in, it would be wiser to leave the materials unprotected until they reached the bridge site, and the remarkable condition of the guard angles on the Alton and the Bellefontaine Bridges would seem to prove this a wise method, notwithstanding its condemnation by general experience and common sense. The only advantage gained is the removal of mill scale and the like by the constant jarring and handling of shipment. It is probable, however, that the incipient rust which must occur at some time begins at the mills and never stops when once begun. The author's proposed method of dipping pieces in oil is logical. One, if not the chief objection to the use of an oil coat, is the difficulty of knowing when it has been applied; the ordinary suggestion to make sure of coating, is to use a pigment and this naturally leads to paint.

That many things are not clearly understood, or are still open to dis-

pute or left to theorizing, is evident at many points in the paper. It seems, for example, more probable that the quality of the material or workmanship in the painting should vary in the several bridges, than that so many of the defects found should be ascribed to failure to clean the structures or to the presence of scale. That the metal had been rolled smoother for the Sioux City Bridge seems also a singularly fortunate ordering for this bridge. Although the paint had about all gone from the cylinders of the Floyd River Bridge, there was little rust, which would seem to demonstrate the folly of using paint in such situations. Exception will certainly be taken to the statement that rust which has not begun to pit will do no harm even if covered up by paint. Mr. Nichols.

Why should a pure oxide of iron paint be purple; and why, being pure, should it fade to the color of shoe blacking? Longitude, or the proximity to salt water, has quite as much to do with permanence of paints as latitude, and structures near the Atlantic coast are in a far more hazardous condition than those located in the great central valleys. The writer does not care to place himself distinctly on the side of red lead as positively as the author has placed himself on the side of iron oxide. The theory, and to some extent the observations, of the writer have been that the iron oxide paints have been less criticised and have appeared at their best because of their color and composition. If an excess of oil exists in the paint it is taken up by the oxide existing on the iron, and as oxidation takes place it has substantially the same color as the paint.

In 1886 he learned of an iron oxide paint made to compete with red lead, from an imported red oxide of iron costing about $50 per ton, when the material for "Prince's metallic paint" was selling at about one-third the price. This paint had been applied to the elevated railroad structure over the New Haven yard in New York City in 1885. Three coats were probably applied, one in the shop and two in the field; the situation was particularly exposed, but the structure has not been repainted since, and is to-day in very fair condition. The same year the old Brooklyn Elevated Railroad structure, 7 miles long, was painted with another iron oxide paint, of whose quality the writer has no knowledge, and he thinks two coats only were used—one at the shops and one in the field. The Brooklyn structure was badly rusted within four years, showing how much depends on the quality of iron paints. The writer once asked a prominent bridge manufacturer what paint he used, and he said he had but one rule: never to use a paint costing less than 75 cents a gallon. With linseed oil at 50 cents a gallon, even oxide of iron paints vary in price from 20 cents to $1 a gallon. One of the most serious objections against the use of oxide of iron paint is the uncertainty of knowing what is obtained, even at the higher prices.

The experience on the Suburban Stem Line structure, now part of

Mr. Nichols. the Manhattan Elevated Railway system, seemed to indicate decided merit in the paint used there, and in providing for new structures in Brooklyn in 1888 it was specified that the paint should be red lead for the shop coat, which had been used in 1887, or the special brand of red mineral paint referred to; the latter, being much the cheaper, was used. As a result, few people have so many acres of rust on exhibition as the citizens of Brooklyn, and it is beyond question that the structure painted with red lead in 1887 is in quite as good condition as that painted with red mineral paint in 1888. Both paints were followed by a second coat of white lead and zinc in light color. It is probable that a third coat of paint would have given much greater protection. The structures seem at first uniformly pitted, and this pitting in bad cases extends finally over broad surfaces, involving ultimately the whole member. The statement that plates are less affected than shapes seems, in this case, to be untrue, and the opposite more nearly the case, since the channels are rarely badly rusted, while the web plates are generally in this condition. The condition varies materially in different girders and seems to depend more on the care in the application of the paint than on any other one thing. Adjacent girders will be, one good, the other bad, without any apparent reason other than such as may be drawn from indefinite theorizing.

The difference in oxidation is marked. Such a thing as "rust under paint," as the writer understands the expression in the paper, is unknown with the red lead paint, which sticks to the iron with remarkable tenacity and always seems tough and keeps the iron bright, excepting where it has been badly eaten by the iron rust. When eaten through in this way the margins about the rust areas are quite sharply defined, while with the red mineral paint the old paint above and about the rust spots seems to loosen up into a sort of spongy mass, forming a cover to small spots or a margin to larger ones.

It is to be regretted that the author's investigation has been so generally confined to structures painted with red oxide of iron. He has evidently found but one case of fair painting with red lead. Some of the Cincinnati Southern bridges should be compared with those at Cairo and at Memphis, age for age, and latitude for latitude, and more should be known of the results of the general use of red lead by European engineers before condemning it in favor of some particular brand of red mineral paint.

Mr. Collingwood. F. Collingwood, M. Am. Soc. C. E.—The paper confirms in a remarkable degree the conclusions of other observers. In every case the author finds that where the protected surfaces were thoroughly cleaned in advance, the iron is in a better condition than where this was neglected or carelessly done. The peroxide of iron cannot by itself rust other iron, but it will hold more or less moisture, and should it be covered in this condition, the oxidation may continue after paint-

ing. It tends also to roughen the surface and prevent close contact of the paint with the surface of the iron. Paint in this condition will surely crack in time, and then the rust that has been covered will absorb moisture and act as a center from which rusting will continue. Mr. Collingwood.

In a paper by Mr. E. Matheson, published in 1882,* he says: "It cannot be too forcibly stated that it is impossible to protect rolled iron by paint without the removal first of the black oxide scales on the surface, and it is interesting to know that this preliminary process is an advantage also in steel." In the subsequent discussion he stated that "undoubtedly if the black scale could be permanently retained on iron it would assist in protecting it, * * * but the scale would not adhere unless the iron was absolutely protected from the air, and paint applied outside the scale became loose with it in a year or two." Mr. William Parker, Chief Surveyor of Lloyds, in a paper on corrosion says also: "Steel or iron should have the black oxide removed, to prevent galvanic action and pitting (in boilers)." He states also that the unequal distribution of manganese in steel probably acts in the same way.

In 1873, the first anchor bars were prepared for the New York and Brooklyn Bridge. The forging of the eyes left a very heavy scale upon them, and this was removed by hammers. They were then pickled in dilute sulphuric acid, next dipped in hot lime water and scoured with brushes, and finally painted with raw linseed oil, followed by boiled oil and iron oxide paint. The coating with raw oil not only covers the surface and penetrates any cracks or inequalities, but it tends to reveal defects instead of covering them up.

Much has been said about the injurious effect of sulphur in paints upon iron, and it is possible that this feeling is carried too far. It has always been understood that the sulphurous gases from the combustion of coal were among the most destructive agencies in their action. It would seem, therefore, that a paint which was itself a sulphate would certainly resist this action upon itself, and if it was inert toward the iron, that it would be an eminently fitting substance to use as a protection.

About 17 years ago a new paint was introduced in England, the principal constituent of which was the sulphate of zinc. In a paper read at that time,† the following statements were made: First, its covering powers exceed by 25% those of the best lead paints, without additional cost; second, it does not yield to the influence of injurious gases; third, it will not blister or crack under the action of the most violent heat; fourth, it contains no poison, and has no odor; fifth, it produces no chemical or galvanic action on metals. The article states that "the paint acts as a true preservative, and does

* See the *Proceedings* of the Institution of Civil Engineers, Vol. LXIX, p. 11.

† See *Engineering*, Vol. XXVI, p. 222.

Mr. Collingwood. not yield to the influence of oxygen, ammonia, sulphureted hydrogen, salt or any other destructive and corrosive agent," and that these statements are endorsed by a number of eminent chemists and others. A notice of the works a year later shows that the consumption of this paint was rapidly increasing and the works were undergoing enlargement. It seems strange that a paint promising so well should not have been introduced here, and it would seem worth the while of those interested in obtaining the best possible preservative for iron work to look up its subsequent history and see whether it sustains the claims made for it.

Mr. Bontecou. D. BONTECOU, M. Am. Soc. C. E.—The paper has great interest as a definite statement of experience to engineers who are charged with bridge maintenance, and is presented at a time when attention has been widely attracted to the unsatisfactory results of usual methods of painting. Previous to 1892 the Kansas City, Fort Scott and Memphis Railroad Company had been using a standard brand of iron oxide paint, which did not prevent rust from showing within three years, and the use of red lead was resorted to. The experience of the company with the latter paint is short, but, so far, more satisfactory. In the summer of 1892 six new spans were painted with a red lead priming coat and a "Prince's mineral" second coat, the work having received only a coat of oil in the shop. The paint has been efficient so far, except on the central portions of the overhead bracing, where coal gas has produced small blisters and incipient rust spots; elsewhere the steel is free from rust under the paint, and there are no signs of failure of any kind.

In order to determine the effect of coal gas on paint five pieces of iron were cleaned, painted and exposed for one year under a bridge of the Kansas City Belt Railway and over a main track, with the following somewhat indefinite results:

No. 1.	Carbon paint..3 coats.....	Paint nearly gone; iron badly pitted.
No. 2.	Carbon paint..1 coat next to metal...	Paint and metal smooth; slight amount of rust under paint.
	Iron oxide.....1 "	
No. 3.	Red lead.....1 " next to metal...	Iron paint gone; lead paint good; metal smooth.
	Iron oxide.....1 "	
No. 4.	Red lead.....2 "	...Paint fair; iron very slightly pitted, and small amount of rust under paint.
No. 5.	Iron oxide.....2 "	Paint gone; iron badly pitted.

It will be seen that the first two and last cases present an anomaly, which can only be explained by the fact that the painted surfaces were only about 19 ft. above the track, and the impact of the cinders from the engine, which was working on a grade, may account for the failure of the carbon paint in case No. 1.

In order to rest conclusions about red lead on a broader ground, the writer communicated in 1894 with a large number of chief engineers

and bridge superintendents who were in a position to have formed opinions of value on the subject. The correspondence developed the fact that the use of iron paints had been considered unsatisfactory in many quarters where red lead was being used and thought to be distinctly better than the iron oxides; while some of those addressed were able to cite definite cases, from their own experience, where red lead had prevented rust for very long periods. Mr. Bontecou.

The paper renders a valuable service in pointing out the importance of applying the first coat of paint to a clean metal surface. Probably most engineers will agree that a shop coat of oil only is best, and that painting over rust will account for many failures. The inference that any good pigment will protect the metal as long as the paint lasts, however, seems to the writer to be misleading, because it rests on another conclusion, that rust found under paint has been there from the time the paint was applied. As rust develops under an inferior paint, breaking out first where the exposure to sun and water is most severe, it is fair to conclude that such paint is pervious, and that even if no rust existed on the metal when the paint was applied, the oxidation would, nevertheless, take place in time. It is not enough that the paint should be hard and tenacious, for if it does not prevent rust these qualities detract from its value by increasing the cost of repainting.

It is probable that final conclusions as to the efficacy of different pigments can only be reached by observing results where all the conditions are known, and if a paint can be selected which will admit of increasing the intervals between repainting bridges, the cost of the paint itself will not be an important element of the case. A good many difficulties about red lead are alleged which, from the standpoint of a somewhat limited experience with it, seem to be overstated, and there is no real difficulty in procuring pure materials or applying them properly and economically.

J. E. Greiner, M. Am. Soc. C. E.—If the statement is accepted that the oxide of iron paint does not cause the iron under it to rust, the author has succeeded in exposing a fallacy. All are aware, however, that a little rust spot, which is oxide of iron, has a tendency to develop into a large rust spot, and as the oxide of iron paint is merely rust mixed with oil, it would appear that there was some foundation in the belief that this kind of paint produces rust on an iron surface. But whether the oxide of iron paint causes the metal under it to rust or not, there are objections to it which can be readily ascertained by any one who will take the trouble to make an inspection over the lines of any railroad which has been using it for the last eight or 10 years. Where one bridge is found the paint of which has stood unimpaired for a period of four years, a dozen bridges will be found which have been painted every two or three years, the paint having apparently dried up and washed off, leaving the iron almost bare. Mr. Greiner.

Mr. Greiner. The good paint and the bad paint are put on by responsible bridge manufacturers, as meeting the usual specification requirements, and the expression used by the author, in his condemnation of red lead, "if it is impossible to buy an honest article of the specified kind, endeavors to get it had better be abandoned for something we can be sure of," would apply more effectively to the oxide of iron paints than to the red lead paints, as the latter can be obtained free from impurities and mixed under personal supervision, without any adulterations whatever, except the addition of a little lampblack, which has beneficial effects. The author's failure to find but a single case where the red lead adhered well or was tough would indicate that in this single case the red lead was pure and mixed with pure linseed oil, properly applied without adulteration. There is no assurance whatever that the other paints which he has classed as red lead paints were of the right quality and prepared in the proper manner, as he himself admits.

Considerable stress has been laid upon the discovery that the white lead mill marks remain on iron, and that red lead, as a general rule, is brittle and easily removed, but it is to be particularly noticed that while they may have been brittle and easily removed, rust spots were rarely found in such cases. This would indicate that the mere fact of the paint becoming somewhat brittle after standing for a number of years is no material defect in itself. Another point that may be noticed here is that cases were discovered where certain rust spots which had become saturated with oil were inactive. In other words, the rust on the iron itself, when saturated with oil, became an iron oxide paint, and protected the metal against further rust. If such is the case, it would seem that structures could be protected just as well by exposing them to the weather for a couple of years, so that they would get a good coat of rust, and then smear some oil over this rust; this would, at least, give an oxide of iron paint, and from the evidence advanced one would be led to suppose that such a treatment would have just as good a result as though the metal had been thoroughly scraped, then covered with a coat of oil, and afterward painted with great care with two coats of oxide of iron paint. It would also be cheaper.

While the writer's experience with red lead is limited, his experience and personal knowledge of the wearing qualities of oxide of iron paint, as ordinarily made, has extended over a sufficient period to have caused him to abandon the use of the latter paint entirely, as being practically worthless except for the sake of appearance immediately after being applied. It must be understood, however, that this statement is to be taken in a general sense, because there are some special brands of oxide of iron paint, sold as proprietary paints, in which the pigment has been very finely ground and pure oil used, which have given what can be considered fairly good results.

Mr. Greiner.

Some of the best results in the use of oxide of iron obtained on the lines of the road with which the writer is connected can be illustrated by the Susquehanna River Bridge, which was painted in 1886. In 1889, three years afterward, the span crossing the Port Deposit and Columbia Railroad was in such bad condition that it required repainting, and it was repainted with one coat of Prince's "metallic brown" and oil. In 1890 or 1891, from four to five years after the application of the first coat of paint, the entire bridge was repainted, and at the present time, three to four years later, the tops of all the chords are in bad condition, and the entire bridge will have to be painted within the year.

Another case, the Schuylkill River Draw Bridge, was painted at the time of the erection, in 1886. In 1890, four years afterward, it was necessary to paint the tops of the chords; in 1892, six years afterward, the entire bridge was painted. At the present time, the paint on the top chords, having stood about three years, is in very bad condition, and within the present year, or three years after the entire bridge was painted, the bridge will be in such condition as to necessitate repainting.

Another case which might be mentioned is the bridge at Grafton, W. Va. This was erected in 1891, covered with a coat of oil in the shops and painted with two coats of oxide of iron paint in the field. Two years later, in 1893, the paint was in such bad condition that the structure had to be repainted. At the present time the paint is in fairly good condition, except that on the tops of upper chords it is slightly blistered.

If any bridgeman be asked how long oxide of iron paint will last, he will be very apt to say it will last about two years, this being the general rule. Engineers' experience with oxide of iron paint has largely led them during the past few years to abandon its use, and substitute in place of it pure red lead with 1 oz. of lampblack to 1 lb. of red lead mixed with pure raw linseed oil, so that there will be from 10 lbs. to 12 lbs. of red lead to 1 gall. of paint. This kind of paint is becoming very general in its application, and where three or four years ago a large portion of the structures were painted with oxide of iron paint, it will be safe to say that at the present time, a larger portion are being painted with red lead. If it could be demonstrated by actual experience that the red lead is no better than the oxide of iron paint, but that it is just as good, the writer would still prefer the red lead because its covering capacity when mixed with lampblack is about twice as great as that of oxide of iron, and when properly applied the total cost of painting, including the paint, is no more per gallon than with the cheaper article.

At the request of the writer, some tests were recently made as to the covering capacity of red lead and lampblack, Burtis, Patterson &

Mr. Greine. Sargent Company's "carbon" paint, and Rinald Brothers' "Bessemer" paint, these paints being used on three different bridges in course of construction. The results of these tests were as follows:

RESULTS OF EXPERIMENTS WITH PAINTS.

	Red lead, 12 lbs.; lampblack, 10 oz.; mixed with pure raw linseed oil to form 1 gall.	Carbon paint; Burtis, Patterson & Sargent Company.	Bessemer paint; Rinald Brothers.
Paint, per gallon	90 cents.	$1 25	$1 50
Labor, putting on	50 "	0 37½	1 00
Covering capacity	600 sq. ft.	600 sq. ft.	720 sq. ft.
Cost per square foot	0.233 cent.	0.271 cent.	0.347 cent.

In connection with the above tests, it is well to bear in mind that the paint was applied by the regular force used for painting structural work at the bridge shop, without showing preference for either kind of paint, care being taken that the iron should be fully covered.

The writer has, during the last two years, examined structures which have been painted with graphite paint, and after four years' exposure, the paint was still in excellent condition. He has seen other samples of graphite paint which, after a few months' exposure, had much the appearance of alligator hide. Asphalt paint in several cases which came under the writer's notice, although of an expensive kind, became practically worthless after having been exposed for less than two years.

In the spring of 1892, some girders were painted with pure red lead and pure raw linseed oil. The writer examined these girders recently, and found that although but one coat of paint had been applied, and that three years ago the paint was just as glossy and fresh looking as though just put on. The ordinary oxide of iron paint, after standing the same length of time, almost invariably shows a dry dirty surface without any gloss or body and can frequently be rubbed off with the bare hand.

A little more or less in the first cost should cut no figure so far as paint is concerned, as it is the wearing quality and protection which is the object in view. Therefore that paint which will give the best protection for the longest period and has a good covering quality is the paint to use. The writer has been using pure red lead, pure raw linseed oil and commercial lampblack, which can be readily obtained, for several years, and while there may be certain preparations of oxide of iron or other paints of a secret nature equally as good, he can as yet see no reason for making a change.

L. J. Le Conte, M. Am. Soc. C. E.—The writer agrees with the author as to the admirable qualities of pure oxide of iron as a pigment, mixed with pure linseed oil. It has all the requirements of a good durable coating and is economical. The recent tirade against this valuable paint is due entirely to adulterated articles which have flooded the market. The adulterant is an artificial oxide of iron, a waste product derived from copperas roasting, notably in the manufacture of sulphuric acid. This waste oxide is full of sulphur, can be bought for little or nothing, and the temptation to adulterate is too much for the average business man to withstand. As a result, it is almost impossible to get a pure oxide of iron pigment in California. Of course, the good name of any paint is liable to be ruined by the market becoming flooded with an adulterated article. The author's remarks about lead paints call to mind a paper written some 10 to 12 years ago in France, and published in *Annales des Ponts et Chaussées*, in which the opinion was expressed that in the case of red lead mixed with linseed oil the chemical action which takes place develops a certain amount of hydrochloric acid, which in turn attacks the iron work. This fact was determined by pricking the first blisters after painting and examining the fluid matter contained therein. This engineer recommended the use of white lead next to the iron, because experiments showed that when mixed with linseed oil the chemical action developed did not give rise to any form of acid. The writer's observations, though limited in extent, tend to corroborate these views. Mr. Le Conte.

Graphite paints are now largely used in California, and so far have a very good record for protecting iron work against rust. The material is absolutely inert, the paints spread to a remarkable degree, and the price is low. As far as experience goes, they adhere well and give every indication of being a very durable class of paints. In short, the writer thinks they are the only paints which stand on the same footing with the good iron oxide paints advocated by the author.

Asphalt paints have not made a good record on the Pacific coast. When applied under shelter they seem to do well enough, but when exposed to the hot, blistering sunlight they go all to pieces and leave nothing but a black powder behind. In extreme cases this disintegration has taken place within six months. The most remarkable fact recorded is how some of these paints successfully withstand sulphurous fumes and actual direct contact with fire in smokestacks, and yet, when exposed to the direct rays of the hot summer sun, they literally crack all to pieces, soon become a black powder and the coating is entirely gone.

N. W. Eayrs, M. Am. Soc. C. E.—Without wishing to detract in any way from the credit due to the author for the care and fidelity with which he has made the examination of the structures mentioned in his paper, the writer ventures to question the accuracy of his conclusion Mr. Eayrs.

Mr. Eayrs. with regard to iron oxide paint. The fact is, the relative value of iron oxide paint and any other good preservative covering cannot be determined by a cursory examination. It is necessary to know the history of the structure, the climatic conditions to which it is exposed, and especially the condition of the metal before the covering was applied, as well as the quality of the paint used.

Since rust was found to a greater or less extent on all structures examined, without regard to the kind of paint used, it is a reasonable assumption that the metal was not perfectly clean when the structures were painted. If it be true, as the author declares, that if rust is "already well developed and of some thickness it will have enough oxidizing agents in its pores to develop more oxide, swell up and crack the paint," it is also a reasonable assumption that the iron oxide in mineral or oxide paints may have sufficient oxidizing agents remaining to continue the rusting process. Natural iron ore, free from sulphur, and ground either with or without roasting, combined with pure linseed oil, undoubtedly makes an excellent covering for metal. Many of the so-called "iron-clad" or mineral paints on the markets are, however, made of inferior materials, and may contain chemicals injurious to the metal. Such paints are made even by reputable manufacturers, and their constituents can only be determined by chemical analysis.

The true way to test the relative value of paints is to apply them under precisely similar conditions as to cleanliness of metal, exposure to weather and other influences, and care in applying the paints. Such a test has been made on a portion of the elevated structure of the Merchants' Bridge Terminal Railway of St. Louis, referred to in the paper under the title of the St. Louis Elevated Railroad. This structure was erected in 1891, from designs and under the care of the then chief engineer, Robert Moore, M. Am. Soc. C. E. At the foot of Wash Street, the elevated structure crosses the Wabash Railroad side tracks. Of the four girders in each of the three spans at this point, the two inner girders are painted with a carbon paint, and the two outside girders with a patent iron oxide paint, which was selected by Mr. Moore after careful analysis of several paints offered, and was used on the entire structure, except at Second Street. The writer is informed that these girders were carefully cleaned before painting. They are evidently exposed to the same corroding action of dampness, and of smoke and gas from locomotives passing under them. A recent examination of these girders shows that the external appearance of the paints was equally good. Both paints adhered well to the metal, although not as well as some iron oxide paints. The carbon paint was, however, more elastic and tougher than the oxide paint. A strip of carbon paint about 3 ins. long and $\frac{1}{4}$ in. wide, cut from the girder, could be rolled into a ball and unrolled several times without breaking, while a similar strip of the oxide paint would usually break on

the second rolling. No blisters or pits appeared on the surface of either paint, but a few spots were discovered under the oxide paint, the location of these being indicated by a slight difference in color. The metal under the carbon paint was found to be bright and clean wherever scraped. It is fair to assume, therefore, that there is no difference in the protective quality of these two paints, although the superior toughness of the carbon paint is a point in its favor. These girders were painted in the summer of 1891. Mr. Eayrs.

The carbon paint referred to is one that has been in use by the Terminal Railroad Association of St. Louis for more than 10 years. It is manufactured from a formula prepared by the master painter of that company, which formula was the result of an extended series of tests made to determine the best covering for the iron work in the St. Louis tunnel. It is made of pulverized charcoal, litharge and the best quality of boiled linseed oil, with the addition of a little borax water. It comes from the manufacturer in a semi-liquid form and is thinned for use with oil alone, no turpentine or drier being used. It is a slow drying paint, and never dries hard and brittle. Paint which had been exposed to the tunnel atmosphere for six years was found to be as elastic and pliable as when first applied. In 1892, the carbon paint was adopted as the standard for all metal structures, whether under ground or above ground.

The overhead crossing of Second Street by the elevated structure and two spans of trestle east of Second Street were painted with red lead and oil; the remainder of the trestle adjoining was painted with the oxide paint. The red lead is considerably discolored with rust spots, and the external appearance is much inferior to that of the adjoining spans. The surface is quite badly pitted with apparently active rust spots, much more so than on adjoining columns and girders painted with the iron oxide, but no worse than on some portions of the elevated structure on the levee, which is also painted with iron oxide. Where the red lead is still in good condition, the metal is clean underneath. It would be interesting to know what was the condition of these spans before painting; how they compared with other spans of the structure which were covered with oxide paint.

The author's remarks on the condition of the Merchants' Bridge in St. Louis are perfectly correct. The bridge is in very bad condition, especially the east span. Where the paint still adheres to the iron it is removed with great difficulty, but the writer is not entirely satisfied that the adhesion is not due to a partial chemical union with the oxide in the paint. In most places the covering is a very thin coat, and where large areas are covered with rust the paint seems to have disappeared through disintegration rather than by scaling off. The bridge will be repainted this spring with carbon paint.

Red lead and oil were used at one time to a considerable extent on

Mr. Eayrs. the girders which carry the upper roadway, or highway floor, of the St. Louis Bridge, but it was found that the heat from the locomotive stacks passing under the girders while the paint was still fresh, "killed" the oil and caused the paint to come off in large flakes soon after it was applied. The use of red lead has been abandoned and carbon paint substituted. This stands the heat much better than any other paint hitherto used.

Every engineer will agree with the author, that in order to protect metal structures to the fullest extent it is necessary, first, that the metal should be thoroughly clean before painting; and second, that the covering selected must be made of a good oil with suitable pigment. The metal should be cleaned and oiled in the shops, as it is impracticable to do this thoroughly in the field. The best quality of linseed oil only should be used in the manufacture of paint, combined with any good pigment which contains nothing injurious to the metal. The writer's preference is for carbon as a pigment for iron work; this contains no sulphur, while many of the iron oxide paints are made from pyrites which do contain sulphur.

Mr. Bouscaren. G. BOUSCAREN, M. Am. Soc. C. E.—Excellent suggestions are made in the paper with regard to the method and precautions to be used in painting iron structures, but it is to be regretted that the author's conclusions should be broader than his foundations. That "pure iron oxide used as a pigment in paint is not a cause of rust on metallic structures exposed to air" is a legitimate deduction from the numerous cases investigated by the author, where the composition of the iron paints used and the method of application were known. That "the present investigation fails to point to red lead as the one pigment above others for painting iron structures exposed to air" is undoubtedly true and the reason obvious; red lead has not been investigated.

The author admits that in all cases of so-called red lead paint investigated by him, the composition of the paint and the manner in which it was applied were unknown to him. "No chemical analysis was made, and the authority for their genuineness is only the specifications, the integrity of the contractor and the color of the pigment."

Under such circumstances the probability is that not a single case of genuine red lead properly applied was examined. No weight can therefore be given to the comparison made between the two kinds of pigments, and the judgment passed as to their relative merit is misleading.

A great deal of attention was given to painting of iron bridges by the writer while in charge of the Cincinnati Southern Railway and associate roads for a period of 11 years, during which different kinds of paint were tried systematically under the same conditions and the same paint under various conditions. The results of these experiments were as follows:

Mr. Bouscaren.

First.—That an essential condition to the preservation of the metal under any kind of paint is that the surface be clean and free from scales and rust; no fair test can be made otherwise.

Second.—That the best covering for the metal before leaving the shop is boiled linseed oil. It will penetrate all joints better without pigment, will not rub off as easily as paint, and will not hide defects which may have escaped detection at the shop. It affords a better foundation than dried paint or the bare iron for the subsequent painting in the field, as it readily incorporates with the first coat and prevents "running." The objection to the raw oil is that it remains sticky and gathers a large amount of cinders in transportation, which must be scraped off before painting.

Third.—That no painting should be done in rainy or freezing weather, otherwise materials and labor are both wasted. New structures, if thoroughly coated with linseed oil, will not suffer by waiting several months after erection for favorable weather to do the painting.

Fourth.—That the best results are obtained when the pigment is ground in oil beforehand. The practice of allowing the painter to mix the paint himself has led invariably to irregular and inferior results. The indiscriminate use of driers is another practice to be avoided. Boiled linseed oil should be the only ingredient used with the ground paint.

When all these conditions have been observed, pure oxide of iron has been found to protect the iron very well under ordinary circumstances for a period of three years, and red lead for a period of six years. Both adhere well to the iron and will not scale or crack. These effects are sure indications of impurities in the materials used, or that the iron was not well cleaned before painting, or that the work was done in an improper manner. Both paints should wear off gradually and uniformly until the coating is reduced to a mere film, when points of rust will begin to make their appearance, which will soon develop into blisters. A fresh coat should be applied before rusting takes place; this will avoid the necessity of scraping, which can never be thoroughly done on a standing structure.

A great deal of the oxide of iron offered in the market contains a large proportion of clay which renders it unfit for the purpose of painting. Chalk and lime are used freely to adulterate red lead, and the writer has personal knowledge of instances when not more than 20% of red lead could be found by analysis in the article delivered under that name for painting. These frauds can easily be avoided by dealing directly with manufacturers of good standing instead of buying from the lowest bidders.

True economy in paint is to use the best materials. As between iron oxide and red lead the writer has a decided preference for the latter, not only because it will last much longer, but especially because it is more uniform in good results.

Mr. Moore. ROBERT MOORE, M. Am. Soc. C. E.—In describing the viaduct built by the Merchants' Bridge Terminal Railway Company, in St. Louis, the writer mentioned* the fact that while the greater part of the structure was painted with iron ore paint, part of it was for purposes of comparison painted with red lead, and he expressed the hope that in a few years definite results of permanent value might thereby be obtained. A recent inspection of the present condition of the paint on this structure revealed the fact that although it is barely four years since the paint was first applied, by far the greater part of it should be renewed during the present year. And to the writer's surprise he found those girders which were painted with red lead to be scaled and pitted worse and to need repainting more than the adjoining ones which were painted with iron ore. As the red lead used was bought by the company for the purpose of a test, and as both paints were applied at the same time, and, so far as known, under the same conditions, the experiment is one of considerable value. There are one or two things, however, which make it not wholly conclusive. Of these the most important is the variable and uncertain condition of the metal when the paint was applied. At the shop all of it was coated with oil. But much of it lay afterward for months on the ground exposed to the action of dirt and water, and before it could be painted was much rusted. While an effort was made to clean it, it was but partly successful, like all efforts of the kind. This fact accounts for the present bad condition of so large a part of the paint and renders the experiment somewhat inconclusive. So far as it goes, however, it points to the superiority of the iron oxide.

As the author indicates, a thorough cleaning of the metal before painting is of the first importance, and for this purpose the writer has long been of the opinion that the sand blast would be extremely useful. It would be rapid and thorough and would reach corners otherwise inaccessible. And if once a portable apparatus were arranged, as could easily be done, it would be cheaper than hand labor. The mechanic who will put such a tool into the market will find a wide field for its use and will merit the thanks of all who have to do with bridge work.

Mr. Purdy. CORYDON T. PURDY, M. Am. Soc. C. E.—All who are to any extent interested in the preservation of structural iron work will welcome the data contained in the paper. In a recent paper, the writer stated† that iron oxide paint should not be used on structural iron. If the author's conclusion can be sustained, the writer will be glad to modify his, which is based on what he could get from the testimony of others and from his own limited observation, but the iron oxide paint, generally used on structural iron work required for buildings, so far as he has been able to observe it, is certainly not desirable, and much of it

* See the *Transactions* of the American Society of Civil Engineers, Vol. XXXI, pp. 500–508.

† See the *Journal* of the Association of Engineering Societies, Vol. XIV, p. 210.

Mr. Purdy.

is exceedingly bad. This examination indicates, however, that the purest and best iron oxide paint is not as bad a paint as its opponents suppose; though it seems as if the testimony in the paper did not warrant the definite conclusion that iron oxide paint is the best, or even that it is better than red lead. The bridges covered with iron oxide paint, which were most thoroughly examined, represent the very best that can be obtained, both in the character of the material and in the application of it, whereas little or nothing is known regarding the character of the red lead paint and the way in which it was applied. This is peculiarly significant when it is recalled that the way in which the red lead is used has very much more to do with its value as a paint than the way in which the iron oxide paint is used; indeed, if the former is not properly put on, its value as a paint is very largely neutralized. Again, it will be noted that many structures were examined which were painted with iron oxide paint, whereas only a few were examined where the red lead was used; also, that all the structures examined are in the interior where paint ought to protect iron if it will protect it anywhere, while if some of these structures had been along the coast, they might not have made as good a showing. At any rate it seems as if corrosion proceeded much more rapidly in salt air than in the drier interior. There are many illustrations about buildings in the vicinity of New York, where in 40, and sometimes even in 20, years rust has entirely eaten through and consumed $\frac{3}{8}$-in. metal.

The whole subject of painting, the characteristics of good paint, the preparation of the iron before the painting, and the proper application of the paint, are more important, however, than the one question whether oxide paint is the very best or not. The author's observations on these kindred questions cannot be made too emphatic. Mr. Morison can control the painting of his bridges in every detail, he can get the very best material, he can secure good inspection and honest work, he can be sure that his iron is clean before the work is done, and he can select his own time for doing it. His good judgment in the matter can control it all, but in many structures, some of them of considerable importance, this is not so, and the cheapest paint is the one that will be used. This lack of authority is especially true with reference to building work, a large part of which is designed without the services of an engineer, except such as may be employed by the contractor. The architect, in many cases, does not fully appreciate the importance of protecting the steel construction against corrosion, and if he does, the chances are that the owner of the building insists upon carrying out his own ideas, which are more likely to be in the wrong than in the right. If an engineer is associated with the architect, he labors under the same disadvantage.

The tonnage of metal going into large buildings has now become very great, and the importance of protecting it has correspondingly

Mr. Purdy. increased. It may be of some interest to the Society to know that all the steel required for the construction of the new hotel to be erected in New York by Mr. John Jacob Astor, must, according to the proposed specifications, receive a coat of pure raw linseed oil at the rolling mills before being allowed on the cars. The plans and specifications of the building have not yet been finally adopted, but there is reason to believe that this provision will be accepted. The building will be one of the largest ever erected in this country, requiring somewhat over 10 000 tons of structural metal. The graphite paint manufactured by the Detroit Graphite Manufacturing Company has also been specified in the belief that it is more to be relied upon than any other paint which could probably be secured for this particular work, if, indeed, it is not the very best which can be had anywhere. The selection was made after a very exhaustive examination into the matter, and on the basis of some extraordinary testimony, from those who have used it.

The author's examination shows quite clearly that rusting as a rule proceeds under paint, even under the best iron oxide paint that can be obtained. If a paint can be made that will cling closely to the iron and that will remain unbroken in all kinds of weather, in heat and cold, and that will not absorb and retain moisture, or in other words, that is entirely impermeable, it seems as if oxidation already begun could be stopped, and it also seems as if the graphite paint promises the most in this particular.

Mr. Melvin. David N. Melvin, M. Am. Soc. C. E.—Having used paints daily in large quantities during the last 20 years, the writer has observed some things in their actions and in the behavior of different compositions which may be of interest, both in bearing out some of the deductions of the author and in helping to find out the best protective paint.

Red lead he abandoned more than 15 years ago for all admixtures and purposes other than as a drier in boiling linseed oil, as he found that under certain conditions of temperature and moisture it formed a chemical combination with the oil, resulting in a body very much resembling sticking plaster. Iron oxide he has since then used invariably for outside use, for roofs, walls, etc. On more than 100 000 ft. of roofing painted with it, no oxidation or rust has been found under the paint, if the paint was in good condition ; that is, had not been injured by walking over it or by other actions it was not intended to withstand. Several of the roofs have rusted through from the inside, but none from the exterior. At the joints where the tin has been soldered and the rosin has not been scraped properly, there has been considerable rusting caused by the paint scaling and cracking off.

Linseed oil has been invariably used to the exclusion of all petroleum products, turpentine or benzole, as these have been found to cause the paint to dry porous and eventually to become cracked; this applies to all kinds of paint.

Mr. Melvin.

The writer has used over 1 000 galls. of linseed oil daily for many years, prepared in several different ways, and has thus had an opportunity of watching the effect of the various methods of treatment. He has found a great difference in the skin of film formed by the drying of the oil, and upon the adhesiveness, permanence, strength and elasticity of this skin will depend very materially the lasting qualities of the paint made from the same oil.

When linseed oil is simply heated with about 3% of litharge or red lead and kept at a temperature of say 350° to 650° for five or six hours and agitated mechanically, or with paddles, as is commonly done, it is then called "boiled oil," and is used promiscuously for painting without any inquiry into the quality of the skin or film it would form when dried. Accordingly as the oil is treated with different driers and at greater or less temperature, and agitated by air blown through it for longer or shorter periods, so the quality of the dry film or skin it will produce is affected as to strength, elasticity, solubility, and other properties. By using a drier of salts or oxide of manganese and continuing the agitation of the oil by air blown through it, as in the Bessemer process, the oil being kept at a comparatively high temperature, say 450° to 500°, the skin may be made to become of a very strong, elastic and durable nature, and perfectly insoluble in either water or benzole.

There is a considerable difference in the albuminous and mucilaginous matter contained in commercial linseed oil, some oils containing nearly 1%, others considerably less, according as the seed has been pressed with hot or cold plates, the amount of pressure given, and the quality of the seed. As to the difference in the quality of commercial linseed oil (always supposing it to be unadulterated purposely) the variation in the amount of these mucilaginous substances or so-called "foots" is the only practical difference the writer has been able to detect; he always overcomes this by blowing air through for longer or shorter periods, and boiling at higher or lower temperatures, as the oil contains more or less foots. If these foots are not removed from the oil before it is used, the effect is to render the dried skin more pervious to moisture and the paint less permanent. Some oil crushers, realizing this, are now filtering these foots out so as to give a pure oil, but it is possible to get rid of them by heat and blowing, and as the oil has to be boiled in any case, one process serves all purposes.

All admixture of rosin, rosin oil, gums or linseed oil substitutes of any sort the writer has always found injurious to the strength and elasticity of the dried film, and the result is a friable resin like rosin, instead of an elastic gum like india-rubber. When a sample of a new oil or linseed oil substitute is submitted for examination, the writer always paints it on coat after coat until it becomes thick enough to judge of the quality of the skin when dry.

Mr. Melvin. Iron oxide paint has had the objection urged against it that it cracks and scales off. The writer never found it so, unless painted over unclean surfaces or mixed with too little oil and daubed on too thickly. If too much pigment is mixed with the oil, especially if the oil has little viscosity, the dry paint is without sufficient elasticity, and will scale off with any change of temperature. Viscosity has great effect on the cracking of all paints, as with a thick oil it is impracticable to put in as much pigment as with a thin fluid oil. With the thicker oil when it dries there is a thicker and more elastic film of oil between the particles of the pigment, giving more play for expansion. With a tolerably viscous oil, the writer has found that equal proportions by weight of oil and iron oxide pigment make a good paint, and he has never found it to crack or scale at this proportion. The manufacturer's analysis of the pigment he has used for the last 20 years is as follows:

Peroxide of iron	52.11
Carbonate of lime	0.27
Silica	46.03
Moisture, etc.	1.59
	100.00

Too great a proportion of carbonate of lime in any paint makes it more easily affected by moisture. Some mixtures made of paris white were so easily affected that they became quite soft every time water was placed on them.

Iron oxide has a drying effect on paint, but the effect is diminished as the amount of it is reduced in proportion to the other ingredients. In one mixture where the writer used the so-called Venetian red and had to use litharge as a drier, by substituting the cheaper oxide pigment he saved the litharge entirely.

White lead he has proved to have the least action upon linseed oil of any pigment of which he makes use; in fact, he can find no other white pigment which will take its place entirely.

Oxide of zinc is a powerful drier, and renders all paints liable to crack; for a paint of ordinary purposes more than 15% of it with white lead cannot be used without risk.

Sulphate of lead, or the so-called sublimed lead, the writer has abandoned altogether, as its action on the oil was very marked, probably from adulteration with zinc, as he had a very strong reaction for zinc in testing it.

Lithophone is a German sulphide of zinc and barium, which is the best he has yet tried, and he now uses about 3 tons per week of this to about the same quantity of white lead.

The covering power of lead paints is much overstated. Equal quantities of oil and oxide of iron make a good covering paint, while

it takes 4 to 1 of oil of either white lead or red lead to cover equally well with the oxide paint. This puts lead paints out of the question when price is to be considered. Mr. Melvin.

The writer sincerely wishes a perfect substitute could be found for white lead, as the poisonous effects on the workmen are very serious, manifesting themselves even after 10 years' absence from contact with it.

A. H. Sabin, Esq.—It is said by people who have much experience and are regarded as of high authority, that the life of a steel frame building is about 30 years, and it is generally agreed by bridge engineers that the most common cause of failure of bridges is the slow corrosion of the bridge members, carried on frequently under several coats of paint, which goes on until the structure becomes weakened below the limit of safety, when a portion must be replaced, or, if it escapes observation, the bridge breaks down. The failure of water mains and pipes to withstand the interior pressure is almost always due to corrosion, as these conductors are commonly strong enough when new to withstand many times the pressure employed, and any serious leakage is usually due to a considerable weakening of the pipe from this cause. Mr. Sabin.

Corrosion means, in this case, some sort of chemical action. Perhaps oxidation is the most common, but it is by no means the only kind. It is well known that chemical action is always accompanied by electrical action, and it is commonly said that electricity is thereby generated. It would be more accurate to say that chemical action is due to unbalanced attractions among the various kinds of atoms or molecules which are in juxtaposition, and the rearrangement of atoms which takes place is accompanied and in many cases caused by a change in the electrical state of the material involved. It is more accurate to say that the chemical attraction between atoms of different substances seems to be correlated to their thermal and electrical conditions, and anything which changes any of these is very likely to change all of them. So it may be that any electrical disturbance will cause corrosion in certain circumstances, though it may not do so in certain other cases. When the great amount of energy is considered which is constantly being developed in the form of electricity, and when it is considered that nearly all is produced by the combustion of coal, and that nearly all this energy can be reconverted, either by purpose or accident, into chemical action again; when the enormous amount of chemical effect is considered which may in the aggregate be caused by even an exceedingly small percentage of the electricity constantly being generated, and the obvious improbability of preventing considerable leakage, it is clear that those having in charge such property as is likely to be damaged by corrosion have a great deal more responsibility now than formerly.

Mr. Sabin. The writer believes that the rusting of iron pipes or other surfaces is promoted by electrical activity in two ways: *First*, and probably most important, by keeping the pipe charged with electricity all the time, thus accelerating the process which would otherwise be very slow, and might in some cases entirely cease by the formation of a protecting coat of some kind, which, however, ceases to protect when the metal is in a state of electrical tension. *Second*, by the passage of a considerable current of electricity by a definite path between the water pipe and some other conductor, the latter being possibly a trolley-car track, or a gas or water pipe having some other electrical connection, or the steel framework of a building or other structure. In this case the corrosion would be more rapid and local; in the former, more insidious and widespread. There is no doubt that heavy cast-iron water pipes which have laid in the ground long without showing signs of corrosion, have from this cause rusted entirely through in many cases, and become worthless.

The writer does not believe that it is right to hold that there is a new kind of corrosion, needing radically different methods for its prevention; but rather that the need for protection against rust is in general greater than before, and that such protection should be more perfect and more stable and lasting than has heretofore been used. Such improvement must be made in two ways—by using the most suitable material, and by applying it in the best manner. The materials which are in use for this purpose are: Oil paints, which consist of various pigments ground or mixed with linseed oil or some substitute therefor; coal tar; asphalt, or mixtures in which asphalt is the characteristic ingredient.

Competent and disinterested persons differ widely in their opinions on these subjects, and tests cannot be compared unless they are made under closely similar conditions. The writer claims only to give an opinion based on considerable practical and some theoretical knowledge of the subject, but does not assume to be infallible; and the following discussion of the merits and demerits of the principal substances used for coating iron leads to a consideration of what is believed to be a practical advance in the art, as well as one which is defensible on a theoretical basis.

Oil paints consist of a pigment of some sort ground in linseed oil or some substitute. The value of the paint depends on the kind of pigment used, and the proportion and character of the oil. The most common of all pigments used for this purpose is oxide of iron, more or less pure. There are three well-defined oxides of iron which occur in quantity in Nature and may be produced artificially, and most oxides consist of mixtures of two or more of these. The magnetic oxide is usually, and perhaps always, black in color, and consists of three equivalents of iron and four of oxygen. This, on account of its

color, is not commonly a principal ingredient. The anhydrous sesqui- Mr. Sabin.
oxide contains two equivalents of iron to three of oxygen; this varies in color from a rather bright red to dark brown or even purple. The common shades are reddish brown. The natural mineral of this composition is known as red hematite, and it is one of the most common ores of iron. The hydrated sesquioxide of iron, known, when a mineral, as brown hematite or limonite, has commonly two or three molecules of water compounded with each molecule of the oxide of iron. This is also the most common form of rust; but iron rust may also contain carbonic acid, making carbonate of iron and some other compounds. Indeed, the number of compounds of iron which may be present in iron rust is legion. Limonite is said to be always a result of the alteration of other ores, such as pyrite, hornblende, etc., through exposure to moisture, air, and carbonic and organic acids, whence it often contains sulphur and phosphorus compounds and organic acids as impurities.

It should therefore be obvious that it is not enough to say that a pigment is oxide of iron. As a matter of fact, the iron oxide used for paint is usually either a mixture of iron oxide with 30 to 70% of clay or other earthy material of complex and usually unknown composition, which easily falls to a fine powder when dry, and is thus cheaply prepared for use; or it is a granular ore, which may be ground to a powder without much difficulty. Iron oxides have to be sold at a low rate and must be made of such materials as can be ground at a reasonable price. These soft and porous ores are the most likely to be impure, both as to admixture of earthy matter and complexity of the iron compounds. These soft and friable ores invariably, so far as the writer knows, contain some hydrated oxide, which is identical with the principal constituent of iron rust. Probably the proposition can be maintained that it is not good policy to cover an iron structure with iron rust as a method of preserving it from rusting, though the same objections might not lie against its application to a wood surface. The hydrated oxide is not the dominant constituent in any of these paints, but little particles of it are scattered through it, and all that is known of the behavior of paints leads to the belief that these softer particles will tend to gather together in little soft, muddy lumps in the mixed paint, and thus will form centers of rusting on the surface to which it is applied.

But some of the iron oxides are made from an ore containing carbonate or some other easily decomposed salt of iron, by a process of roasting. The writer had experience, some years ago, in running one of these roasting plants, and knows something about it practically. In theory, all the iron should be reduced to a uniform state of oxidation; and when it is ground and put into barrels the samples do appear to be tolerably uniform. But an examination of the ore as it comes out

Mr. Sabin. of the roasting apparatus shows numerous particles, especially in the interior of lumps, which are different in color and in composition from the rest; and the writer has never seen a batch without some portions which were but partially decomposed. It is customary to pick out the worst of these and reject them, but it is impossible to do this thoroughly and it is impracticable to do much of it, as it would increase the expense. The presence of these hydrated lumps is due partly to unequal heating and partly to the presence of some iron compounds which are decomposed only with considerable difficulty. Mixed frequently with the iron ore is enough clay to make 40 to 70% of the resulting pigment, and this is an advantage to the paint grinder, as it makes his pigment lighter and tends to keep it from settling.

The writer is disposed to think that it is the presence of these little bits of hydrate which form the well-known and practically universal rust centers found under iron oxide paints. But it would be a mistake to suppose that sesquioxide of iron itself is as unchangeable as silica, for instance. It is said in Watt's "Dictionary of Chemistry" that "even at ordinary temperatures it frequently acts as an oxidizing agent in contact with organic matter, and is thereby reduced to magnetic oxide, or even to ferrous oxide, and then, by taking up carbonic acid, converted into spathic iron; the reduced oxide, if in contact with moisture, is frequently also reconverted into ferric hydrate by atmospheric oxidation. The oxide is also sometimes further reduced by the action of sulphydric acid, and converted into pyrites." Any such action as indicated above would tend to injure the oil, and make the paint brittle and incline it to crack, and in extreme cases to peel. A very large amount of artificial oxides of iron is sold in this country. These are made from copperas and various by-products, and are usually mixed with lime to neutralize any free acid which may be present; they contain frequently an excess of sulphate of lime and other things as adulterants. These pigments are usually bright in color, as bright colors sell for more; but the brighter they are, the more hydrates they contain. The hydrates of iron contain, roughly speaking, from 10 to 14% of combined water, which is in a rather loose state of combination. Such compounds, which pass from one state of oxidation to another, act as carriers of oxygen, which is the commonly received explanation of the progressive action of rust.

The chemical problems involved in the use of paints having white or red lead as pigments are very obscure. It is well known that lead oxides (and white lead, which is a mixture of carbonate and hydrate, probably behaves somewhat as an oxide) combine with oil to form soaps, which are salts in which the acid of the oil unites with the lead of the oxide. The addition of lead compounds to oil increases its rate of drying whether heat be used to combine them or not; but the amount of lead in boiled oil is only from about 1 to 5% as a rule, and

it is heated strongly with the oil. Such oil is much less durable than raw oil without driers. The amount of lead required to fully decompose the oil is about 40%; but in making red lead paint ten times this amount is used. No investigation of the results of this practice has come to the writer's notice, but a few observations may be in order. Mr. Sabin.

First, the paint is red. This is proof to the writer that a large amount of the red lead is present as a pigment, and it is known to be charged to a very high degree with oxygen.

Second, the paint dries almost immediately. Hence some of the lead combines with the oil, none of which dries by the usual gradual process, and it seems almost certain that the "binder" in this paint is a lead soap instead of the usual linoxyn film. It is characteristic of red lead that when mixed with linseed oil it "sets" into a compact mass in a comparatively short time, which is a practical difficulty in its application. Some of the ways to avoid this will be mentioned later.

This leads back to the fundamental question: Is this lead soap a better binder than ordinary oxidized oil? From all that is known of the behavior of oil to which comparatively small quantities of lead have been added, it seems highly improbable; still it is a practical and not a theoretical question. As regards the use of white lead, there is less dispute. This pigment has long been the standard white on account of its fine color, its great opacity or "body," and the ease with which it is applied. But when exposed to the weather, all agree that it lacks permanence. The oil is converted into a crumbling soap, and the pigment washes or brushes off. As painters say, it "chalks." It is probably the most perishable paint used by house painters.

Carbon in some form, usually as graphite, is used to some extent as a pigment for anti-rust paints. There are two objections to the use of graphite for this purpose, one of which is that as it is the lightest natural substance in use as a pigment, it is not possible to get a considerable percentage of it into oil. And second, it is a flaky and greasy substance, which cannot be ground fine economically, and it settles out of the oil very badly. A purely sentimental objection to it, which is only a cause for suspicion, is that it owes its introduction almost wholly to the efforts of manufacturers of graphite pencils and similar goods, not interested in the paint business at all, to get rid of a lot of their waste product. On the other hand, graphite itself is a very permanent and neutral substance, and some who have used it report very favorably, while others do not. If it is valuable it is an exception to the almost universal rule that the pigment in a paint is more valuable the more finely it is ground and the larger it is in quantity. Oil dries by a process of oxidation, and this leaves the film full of minute pores, and one of the offices of the pigment is to fill up these pores, and thus render the film more continuous. The finer it is, the better it will do this. Also, the pigment increases the "body" of the mixture, so that it is

Mr. Sabin. possible to apply a much thicker film. In this way it acts as a spongy substance, and the finer it is, the better. It serves to make the resulting dry film harder than oil alone would be, exactly as a pavement composed of 80% sand and limestone with 20% asphalt is more durable than one of asphalt alone. These are the principal ways in which a pigment is useful in a paint; and in all these respects graphite is unsuitable. Linseed oil alone affords considerable protection, and it is possible that where good results have been had from graphitic paint a film of oil would have been equally efficient.

Perhaps even more important than the nature of the pigment is the quality of the oil used. The best quality of linseed oil is obtained from pure seed by pressure at a not very high temperature. The oil thus obtained is mixed with some watery juice and mucilaginous and other vegetable matters, from which it separates by standing, and it is then filtered off into tanks where it is kept in warm storage for from one to three months, or sometimes longer. It is found that a considerable sediment settles out, leaving the oil bright and clear and free from moisture. It does not require much capital to build an oil mill, and if the oil can be sold as soon as pressed it does not take much capital to run the business, for oil is sold usually for cash or on very short time. But if it is kept in storage for two or three months it takes considerable capital. One Brooklyn company has storage for 3 000 000 galls. The natural result is that a great deal of oil is sold without proper curing, and after the pigment is put into it, it is hard to find out what is the matter. Further, a great deal of the seed contains a mixture of foreign seeds, such as wild mustard and other weeds, in such quantity that cattle will not eat the oil-cake. And while the adulteration is unintentional, and the oil is commercially called pure, it is very inferior to really pure oil. There is a steady demand for really pure seed by oil-makers for the varnish trade, who get a good price for their oil, and the result is that all impure seed goes into the manufacture of such oil as is sold on price alone. Consequently the makers of high-grade paints have to pay more than the bottom price for oil, and high-grade paints are practically never put on structural iron work, because the consumer will not pay for them, When the purchaser buys a "pure" pigment, ground in commercially "pure" oil, he naturally thinks he has received the best possible goods. But his belief is not commonly founded on knowledge.

There are many large users of paint, such as the railroad companies, who buy their pigments and oil separately and mix them. Such concerns often use boiled oil. Boiled oil does not mean anything definite. The old practice was to put linseed oil in a kettle and heat it to a temperature of 400° or 500°, at which it was said to boil. Linseed oil never boils, however; when it becomes hot enough it is decomposed by the heat and bubbles of permanent gas come off. The heat in the

old practice was only sufficient to attack the foreign vegetable matters in the oil, and at that point some lead and manganese compounds—usually oxides—were added, and these combined with the oil, making it darker in color, heavier in body, and much more active in drying. There was a great difference in these prepared oils, depending chiefly on the amount of metallic oxides used and the amount of cooking. But all such oils are inferior in durability to pure raw oil, for every bit of drier added to oil lessens its permanence. It is supposed that these oxides act as carriers of oxygen, enabling the oxygen of the air to combine with the oil; and their injurious effect is due to their enabling the oxygen to continue its action on the oil after the latter has absorbed the normal amount. So that the best boiled oil is less valuable than the raw oil from which it was made. Boiled oil is now commonly made by adding a few gallons of a liquid japan drier to every barrel of raw oil, which is then said, in factory parlance, to be "boiled through the bung hole." This is really to be classed as an adulteration, for such oil is commonly said to be worse than that which has been treated in the kettle. Of course, the painter prefers it, because the paint dries more rapidly, and that is the reason it is used. But another objection to its use is that it is very difficult, and in many cases impossible, to detect adulterations. One of the commonest of these is to mix in about 30 to 50% of fish oil which has been also treated liberally with driers; and another and still more common mode of adulteration is to add a mixture of mineral oil, rosin and driers, equal in amount to a third or half of the whole, and the writer has no doubt but that some mixed paints are sold which have no linseed oil whatever in them. One of the largest paint concerns in this country makes ready mixed red lead paint under a patented process by substituting a considerable amount of glycerine for part of the oil. Another manufacturer puts in 1 lb. of white zinc to 3 lbs. of red lead, and one of the largest bridges in the world was painted with "pure red lead" paint in which the pigment consisted of 2 lbs. of whiting to 1 lb. of red lead. The writer also knows of a government contract for a very large amount of pure white lead which went to a contractor who supplied a paint in which the pigment consisted of 100 lbs. of white lead to 1 000 lbs. of barytes, and there is a well-known brand of non-magnetic iron oxide which is said to contain 72% of iron when the theoretical maximum is 70%, and, as a matter of fact, the pigment in question contains not over 25 per cent. A letter to one of the largest contractors in New York was recently shown the writer, offering pure oxide mixed paint for 45 cents per gallon, when ordinary oil was worth 56 cents, and it is often said that oxide paints can be made at a cost of 45 cents to 55 cents per gallon. The writer has some practical knowledge of the cost of paint grinding, and he has lately gone over this matter with the superintendent of one of the largest and

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Mr. Sabin. best paint factories in the country, trying to get at the absolute minimum cost of such a paint. In the first place, a gallon of paint contains about 6¼ lbs. of oxide, worth, say, 9½ cents, and 6¼ lbs. of oil, which, at 56 cents per gallon, is worth about 46½ cents, making 56 cents for material. Now, if it is mixed in a paint mixer, not ground through a mill as it ought to be, but as it is not usually, and is made in large quantities, the cost of labor and power may be figured down to, perhaps, 1¼ cents per gallon, without allowing anything for supervision; ¼ cent per gallon must be added for wear and tear; it costs at least 2 cents per gallon for barrels, and 1½ cents to deliver it F. O. B. in New York, making in all 5 cents per gallon. If to this is made an allowance for superintendence, rent, insurance and interest on capital invested, at least 5 cents more must be added, making the actual cost under the most favorable circumstances 66 cents per gallon. If it is to be put through a mill, the cost of labor and power will be not less than 2 cents per gallon additional, with another addition for superintendence, etc., which would bring the cost up to 70 cents. But in any manufacturing business there is more or less loss of material and of time, and there must be also some little profit; and it was the opinion of the expert that any man who attempted to sell a perfectly straight well-made oxide at 75 cents per gallon would lose money. In the factory where he is superintendent it is necessary to grind certain cheap paints and deliver them, without packages, to another department of the same factory; and it is customary to charge the second department 1 cent per pound for grinding, which, in this case, would be 12½ cents per gallon, which is the estimated actual cost; this substantially agrees with the figures given. A large manufacturer in Canada, where labor is cheaper than here, contracted to have his liquid paints ground and put into the packages which he furnished for 2 cents per pound for labor only, which would be 25 cents per gallon on oxide paints; this was cheaper than he could do it himself and proved to be too little to remunerate the contractor.

The cost of a gallon of pure red lead paint, very hastily and imperfectly mixed (as it must be) just before using, cannot be less than $1 50 per gallon, and probably is a good deal more than that. The exact cost cannot be computed without knowing the amount of pigment used, in regard to which practice is variable; but 20 lbs. per gallon makes a very thin paint. The cost may run up to $2 per gallon. This question of cost of paint is of more importance than it might seem at first sight, for it is evident that a very cheap paint is not what it is pretended to be, and, if so, doubt is at once thrown on its whole value. As a general rule, no really first-class goods can be made without skilled labor, and the more skilled labor used, the greater will be the cost. A thing is not good merely because it is expensive; but if it is a thing which is capable of being made better by skill, then the best

of the sort cannot be cheap, and is yet likely to be most economical in use. When paint is offered at 45 cents per gallon the price is against it, and it is easy to make a paint which is honestly worth, from the manufacturer's standpoint, $1 50 per gallon. Indeed, there are enamel paints which are ground in varnish which are worth from $8 to $12 per gallon, and cannot be honestly made and sold for less. It is worthy of notice that the practice is almost universal of thinning oil paint with turpentine or benzine. This is an adulteration, whether intentionally so or not. Often it is done to make the paint spread more freely, but the result in all cases is to make a thinner film of dry paint, and when a pigment of great body is used, as is commonly the case, an exceedingly thin film will cover up the iron. From this point of view a less opaque paint would be better, as it would then be impossible for the painter to apply so little. A good heavy coat of oil paint is better than an excessively thin one, and if a manufacturer claims that a gallon of paint will cover 600 to 800 sq. ft., he is advising the use of a coating of not much more than a half to two-thirds the proper thickness. A gallon of any paint will cover that surface if it is made thin enough. Mr. Sabin.

Coal tar is the next preserving agent to be considered. The most important fact in regard to coal tar is contained in these words, taken from Ure's "Dictionary of Arts," and written more than 40 years ago: "Factitious tar and pitch, being generated by the force of fire, seem to have a propensity to decompose by the joint agency of water and air, whereas mineral pitch has been known to remain for ages without alteration." In the first place, coal tar is a product of distillation, and, with the exception of a considerable amount of soot, it has been condensed from a state of vapor; the inference is that it can be converted into vapor again, leaving the uncombined carbon behind. Next, it is to be considered that tar from different works differs widely in physical and chemical characters. The standard books on chemistry give lists of at least 100 different compounds contained in coal tar, and there is one chemical factory in Germany where more than 100 products are made from it; there is an uncounted myriad of things made from it by more elaborate processes, including analine and azo dyestuffs, carbolic and many other acids, and a large proportion of the most complex chemical substances known. By making it from different kinds of coal, or different mixtures of coal, or by using different degrees of heat in the gas retorts or in the condensers, products are obtained which are all called and sold as coal-tar, yet differ widely in every way, except that they are all black, and sticky, and cheap. The manufacturer of secondary products has to take great care to buy exactly the kind he can get his particular class of products from; but to the engineer it is all alike coal-tar, and all equally useful to apply to his iron-work. The writer has seen certain kinds of it, thinned with

Mr. Sabin. benzine, sold at 16 cents per gallon for a smokestack varnish, and the purchaser thought himself abused because it was not durable. Simplicity and durability are very closely connected, and there is nothing known to man that compares for a moment in complexity with any of the unsavory messes called coal-tar. The primary reason for using it is that it costs practically nothing. It is easily applied, it is adhesive, it is not possible to dissolve all of it off with water, and it usually preserves the pipes (for it is used almost exclusively on pipes) from rusting until they are out of sight in the ground. Probably every one has seen many pipes dug up from which all signs of it have been removed, but often there is enough soot and other insoluble matter to show a black film after many years. In some cases, from some peculiar and accidental composition of the coal-tar which chanced to be used, this residuary film may have had some protecting action; but a majority of cases are like one described by Mr. Birdsall, Chief Engineer of the New York City Department of Public Works. A pipe which had been down 18 years was taken up, and was in a fair state of preservation, and the coal-tar film was also nearly intact, but there was an appreciable space between the black film and the surface of the pipe. The metal in such cases is preserved simply because there happens to be nothing present sufficiently active to corrode the cast-iron, and also because there is so much iron there.

The original process for treating water pipe which was recommended by Dr. Angus Smith, specified that a considerable amount of linseed oil should be mixed with the tar; this no doubt improved it somewhat, but the writer cannot learn that it is ever used at present, and doubts if it ever was of much value. Attempts have been made to substitute coal-tar for asphalt in pavements, but the tar has invariably proved worthless, being subject to rapid and certain deterioration, though it always remains black, as it does on water pipes. It is also compounded with dead-oil, rosin, benzine and other things to make a paint which is miscalled asphalt paint, but has absolutely no asphalt in it. It is a great abuse of asphalt to confound it with coal-tar. Asphalt is a mineral, or rather a class of minerals, intermediate between the petroleum oils, from which many geologists think it is derived, and bituminous coal, and seeming to shade off gradually into both. Dana says, in his "System of Mineralogy," that "petroleum passes by insensible gradations into pit-asphalt or maltha; and the latter as insensibly into asphalt or solid bitumen. The fluid kinds change into the solid by the loss of a vaporizable portion on exposure, and also by a process of oxidation, which consists first in a loss of hydrogen, and finally in the oxygenation of a portion of the mass." Maltha is an old Greek name first applied to the more fluid and tar-like bitumen by Pliny, and is still used with that meaning; and the substances known by this name are closely related to the naphtha oils, from which they

differ in having greater viscidity, deeper color, and higher specific gravity and atomic weight. They are said by Dana to enter into the constitution of all free-flowing petroleums, but are especially characteristic of the denser kinds and viscid bitumens, and exist also in many asphalts. Some of them are separated from petroleum in the ordinary process of distillation as a residue left in the retort; the California maltha is of this character, and is not to be confounded with coal-tar or coal-tar pitch, which it resembles in appearance. These artificially prepared bitumens are soft, and differ in important respects from the natural hard asphalts. Chemists and mineralogists formerly had a theory that asphalts in general were mixtures of two substances, one an oily compound, called petrolene, and the other a fusible solid called asphaltene; and that they differed only in the proportions of these two ingredients. This view is still held as substantially correct, except that there are several of the softer or more oily constituents instead of one, and also probably several of the harder components differing chiefly in degree of oxidation. The harder asphalts exist in large masses, that at Trinidad being of great depth, and the veins of gilsonite being several feet in thickness and imbedded in the earth; it is therefore protected from atmospheric agencies except superficially, and the superficial portions are of less value than the rest. The way in which it has reached its present constitution is unknown, and so is its origin. All that is known with certainty is that some kinds of asphalts are suited for certain purposes and others are not; and knowing their composition, a theory can be advanced to explain the facts, but it must be remembered that the facts are surer than the theory, and that should the theory be successfully attacked, the facts would remain the same. Briefly, then, the theory proposed is that the toughness of asphalt is largely due to its more fluid constituents, and that when spread out in a film, as a paint, it loses these by evaporation or otherwise, and becomes friable and crumbly, and easily falls to a powder. This may be tested by dissolving any asphalt in turpentine or bisulphide of carbon to a thin liquid and painting it out as a thin film on a piece of metal which is exposed to the weather. In a few days, or weeks at the most, it can all be rubbed off as a brown powder. It is natural to expect that the hard asphalts would reach this condition first, and this might lead to the conclusion that the softer kinds would be the most valuable; but the opposite conclusion is the true one, as will be shown; for if the asphalt coating goes to pieces, as it evidently does, from the loss of its softening and toughening ingredient, the obvious remedy is to replace the latter with some elastic matter of greater permanence; and such a constituent is found in linseed oil, which when oxidized becomes a tough substance of the very greatest durability. A hard asphalt can be combined with a maximum quantity of oil, while to a soft one, which is charged

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Mr. Sabin. with a portion of perishable oily matter, it is possible to add but little of the more permanent elastic constituent, and the compound thus made will undergo a rapid change upon exposure, which is not the case with the other, which quickly comes to a permanent condition by a process of oxidation like any other well-made paint or varnish.

This leads to the consideration of solutions of asphalt and other bitumen in turpentine, benzine and other solvents, used as a varnish. Many of these preparations contain rosin, which is added to improve their appearance and also makes them cheaper, but is detrimental in every other way. Some of these are true oil varnishes, in which the asphalt acts as a sort of mineral resin and frequently is compounded with fossil resins and properly combined with linseed oil, and these are very durable; but a solution of any of the bitumens alone in a solvent is certain to undergo decomposition by the evaporation of the solvent when exposed in a thin film to the weather. In these cases greater comparative durability is reached by employing a soft bitumen, such as maltha or pit-asphalt, because the very heavy mineral oil in it is removed somewhat slowly; if the coating is very thick some of it remains for a considerable time, but its disintegration is steady and certain.

The practice of using considerable quantities of benzine or bisulphide of carbon in these mixtures, aside from its fire risk and other objectionable qualities, is open to the following objection, first pointed out by Mr. M. P. Wood. The rapid evaporation of the solvent during the application of the coating lowers the temperature of the metal and consequently of the adjacent surface, and if at the time the atmosphere is nearly saturated with moisture the metal will be cooled below the dew point and a thin invisible film of dew will be deposited on the surface which is then quickly covered with the paint, thus preventing perfect adhesion and supplying a favorable condition for corrosion. This seems to the writer a very serious matter, and may explain the fact that in some cases the use of such preparations has been much more unsatisfactory than in others. This may be one cause of the well-known inferiority of benzine to turpentine as a vehicle in varnishes; the latter may be put into the varnish at a high temperature, and unites with it more than benzine does, besides which it has both a higher boiling point and much less diffusive power, and it evaporates very slowly. On account of its low boiling point and high diffusive power, carbon bisulphide is worse in this respect than benzine, besides which more than four-fifths of it is sulphur, making it one of the most powerful sulphurizing agents known, and it is for that purpose it is chiefly used.

It has long been known to varnish-makers that the fossil resins known as copals, such as the New Zealand Kauri, when added to asphalt varnishes improve their durability. This is probably partly

owing to the fact that such compounds are of greater density, as the resin dissolved in the oil and asphalt tends to make it a more compact substance, and partly because it increases its electrical insulating power, and also in considerable measure because such a resin is very indifferent to the action of sulphur gases. For all these reasons it seems to the writer that the maximum of durability is only to be reached by a compound of hard asphaltum, copal gum and linseed oil, thinned, if necessary, with pure turpentine. It is of the highest importance that the oil employed should be pure, and also that it should be so refined as to have its non-drying constituents removed, so as to avoid as much as possible the use of driers. This is of more importance than in a pigment and oil paint, because the most obvious thing about asphalt is mentioned in the observation of M. Riffault, made some 30 or 40 years ago, that "asphalt destroys the drying quality of oil." This is due to the fact that, being a viscous substance, it closes the pores of the oil and thus obstructs the entrance of air and moisture, which is again the cause of the great durability of such compounds. Mr. Sabin.

Not only is it necessary to have the most suitable materials in such proportions as experience has shown to be best, but the ingredients should be compounded in the most approved manner. Long experience has shown that there are certain temperature curves to be followed in combining certain materials, differing for different compounds, a departure from which injures the durability of the resultant compound. The upper parts of these curves approach dangerously near to the decomposing point of the oil, and as it has been found that a suitably refined pure oil has this point more than 100° Fahr. higher than common oil, it is on this account also important to use the highest skill in the manufacture. The choice of ingredients is of less importance than their proper proportion, and this again is of no more value than the use of the best process of combination.

The best coating for iron work should have a kind of toughness which does not depend on a perishable ingredient, and is, therefore, not rapidly affected by age; its elasticity should not be lessened by cold; it should not soften but rather harden by heat; it should contain no solvent except turpentine, which experience has shown to be neither disagreeable nor dangerous in its usual application; and it should contain nothing which will have a corrosive action on the iron, nor act as a go-between to carry oxygen from the air to the metal. It ought to last forever, but nothing has yet been discovered which fulfills this condition, although it is now possible to make compounds of great permanence. It ought also to act as an insulator. These conditions are well satisfied by a compound such as has been described.

It has long been the custom to apply the coating material as a liquid at ordinary temperatures with a brush to the surface, more or

Mr. Sabin. less clean, of the metal. It is justly regarded as important that the surface should be clean, for the reason that incipient rust spots eat into the iron by acting as carriers of oxygen from the air. This assumes that the air can penetrate through the paint, which is generally true. It is plain that if the paint were absolutely impervious this process could not go on, and as it is practically impossible in most instances to have the surface absolutely clean, it is of importance to have the coating as continuous as possible. It is further desirable to have a paint which, if applied with a brush, will dry with sufficient slowness to flow freely and not set, and yet will dry soon enough to be safely applied in ordinary seasons, whether cold or warm weather. In view of the fact that all these coatings are somewhat porous, it is desirable to apply at least two coats, allowing plenty of time for the first to harden, so that the second coat may fill up the pores in the first.

For some work, especially for water pipes, there is a much better way of applying the material, namely, by dipping the pipe or other object in a vat of the coating compound and then putting it into an oven and baking it. This process, known as japanning, has long been applied to small articles, such as door locks and latches, metal sign plates and small pieces of machinery, such as sewing-machines; and when good material was used in the right manner it gave a high degree of durability, the coating usually outlasting the usefulness of the article which it protected. This is because the coating is kept in a fused or plastic condition, and is protected from the weather during its entire period of oxidation. This condition promotes its intimate and continuous contact with the surface of the metal, and an entire absence of porosity. It is found also that such a coating acquires hardness without losing toughness, and, as it has a very smooth surface, it resists abrasion to a remarkable degree. This process of baking is capable of very wide application. If a surface of metal or wood is coated with an ordinary varnish of good quality and is baked, even though the temperature may not exceed 200° or 225° Fahr., its durability is enormously greater than if dried in the ordinary manner, and this process is now applied in the use of varnish on woodwork by some of the piano makers. There can be no doubt that a properly made baked coating greatly excels in durability any coating not so treated. It is reasonable to expect, and it has been empirically proved, that a compound which requires a high temperature to harden it is the most durable, for the change induced by the heat is not one of evaporation, but is a chemical one, and if the compound yields only to high heat it is an indication that it strongly resists all influences tending to produce chemical change.

The application of this process to very large work involved some important changes in the process and materials of manufacture, but

the difficulties were successfully overcome, and about 14 miles of 38-in. riveted steel pipe was satisfactorily coated for the city of Rochester. The evident value of this coating led to its subsequent adoption by the city of Cambridge, Mass., where about 4½ miles of 40-in. steel pipe is now being made and coated; and the same coating has been adopted by the authorities of Allegheny, Pa., for 50 000 ft. of 5-ft. pipe. It is also likely to be used for other large work in the near future. The Allegheny work is not yet actually under way, although it will be very soon; but the Cambridge work is being done by Edward Kendall & Sons of Cambridgeport, the plant consisting of a vertical cylindrical steel tank, steam heated, for holding the liquid, this tank being about 33 ft. in depth and a little over 4 ft. in diameter. Adjacent to this is the oven, about 12 x 20 ft. on the ground, 33 ft. high, with openings in the top for eight pipe sections, the openings being covered with removable lids. The pipes are first put into the oven a few minutes to warm, then lifted out and dipped, replaced in the oven and baked for two or three hours at a temperature of 450 to 500° Fahr., this temperature having been found suitable for the proper hardening of the compound used. If for any reason so high a heat is objectionable on any special work, the coating compound could be modified so as to conform to the conditions indicated. Mr. Sabin.

The oven is of brick, with an iron roof covered with cement and gravel, and the lids covering the holes are of light steel backed with asbestos and wood. The oven is heated with four fuel-oil burners, and the products of combustion escape into the open chamber of the oven, thus utilizing the heat fully. There is no danger of fire. It is necessary to have so many burners only to be able to get up the heat quickly; comparatively little fuel is required after the oven is hot. The process is simple and gives uniform results, but needs constant and intelligent supervision, particularly for securing uniformity of heat. The pipe sections are 28 ft. long, made of three sheets of ⅜-in. steel plate; and after placing in the trench they are field-riveted together. The rivet heads and some of the surfaces of these field points are then painted with a sort of varnish made expressly for the purpose, containing the same ingredients as the baked coating, but thinned with turpentine so that it may be easily applied with a brush. While this is probably not quite so durable as the baked coating, it has been so satisfactory that it is now used largely for painting bridges and structural steel work of buildings. It has been suggested by William Jackson, M. Am. Soc. C. E., that the pipe sections might be made with pressed steel flanges and put together with suitable packings, so as to avoid the use of any but the baked coating.

Extracts from a letter dated April 25th, 1895, from E. Kuichling, M. Am. Soc. C. E., are appended, which give the result of tests made by him during the past two years.

Mr. Sabin. "In relation to the experiments which I made with your japan coating, and also with a number of asphaltic paints. The first samples which you sent me (small sections of 1-in. cast-iron pipe), were subjected to tests by immersion in moderately alkaline and acid water. I cannot describe the strength of these solutions exactly, but will give them in popular language. About ¼ oz. of caustic soda was put into 1 quart of water to form the alkaline mixture, and about the same amount of hydrochloric acid in 1 quart of water to form the acid mixture. A sample was placed in each of these solutions in fruit jars and kept therein for about one month. No change in the quality of the coating could be detected at the end of this time. The two samples were then buried about 3 ins. below the surface of a richly manured garden soil, and were allowed to remain therein about one year, during which time they were frequently dug up and examined. No sign of deterioration or rust appeared. It was, however, necessary to reach some decision about using the coating earlier, and during the first month of the burial of the two samples, the ground was regularly watered every day with both fresh water and small additions of ammonia in water to stimulate the growth of the ground bacteria, with a view to ascertaining whether such organisms would have any action upon the coating. This was done in the summer time when the conditions were most favorable for the growth of such organisms. No change in the coating, however, could be detected, even with the aid of a powerful magnifying glass. For the remainder of the season (1893) the same treatment of watering was kept up, but not with the same regularity as before, and during the winter and following spring the samples were left undisturbed in the ground. They were again exhumed for examination early in June, 1894, and the coating was still found to be intact, although the gloss seemed to have been slightly reduced. They were then replaced in the soil and examined the following October, but no perceptible change had taken place. With the expectation of subjecting them to a severer test, the two samples were then set vertically in the ground with their tops projecting somewhat, and remained so until March, 1895, when they were examined casually and found to be still in excellent condition. On looking for them early in April, however, they could not be found, and were, doubtless, removed by the gardener, and thus lost.

"Almost identically the same experience was had with two samples of 2-in. pipe coated in August or September, 1893, at the Rochester Bridge and Iron Works, by your process, the coating in this case also remaining practically unchanged during the entire period up to April, 1895. We have thus a record of nearly two years' usage under worse conditions than probably occur in the subsoil where a large pipe is buried.

"Another experiment consisted in placing a sample of coated pipe in a jar of water and leaving it therein for two months, renewing the water occasionally; and still another experiment was in suspending a sample of coated pipe in the air on the roof of the building in which my office is located, in such manner that it was fully exposed to the weather, and frequently also to the smoke and fumes from the chimney of the building. No change in the coating appeared in this sample after six months' exposure, when it was finally blown from its fastenings during a hurricane, but was recovered after having broken through the skylight of the adjacent building.

"While these experiments were in progress early in 1893, similar ones were made with a variety of asphaltic paints or varnishes, ap-

plied with a brush, like paint, to small pieces of thin sheet iron. None of these experiments were satisfactory, especially those in which the samples were exposed to the air, as above described, or where they were buried in the ground. A few weeks usually sufficed to produce extensive rusting and a marked deterioration of the coating material itself. Mr. Sabin.

"I regret greatly that I have not yet been able to obtain from Mr. Alden the record of the experiments which he made independently with similar samples of pipe coated by your process, in the fall of 1893. I can, however, say that he subjected such samples to the following tests: 1. A solution of caustic soda, of moderate strength. 2. A solution of common salt, somewhat stronger than sea water. 3. The action of stagnant water, the sample being placed in a fruit jar and left so for weeks. 4. The action of running water, the sample being suspended under the faucet of a wash basin or sink. 5. The action of ammonia and organic salts, by placing a sample in the urinal of his office building containing about eight occupants. 6. The action of sulphur fumes from ordinary bituminous coal, by suspending a sample over the forge used for making or heating rivets. 7. Burial in the ground where hot water and oil condensed from the exhaust of a steam engine would drip to considerable extent. All of these samples were left in place for more than three months without showing any rust or appreciable deterioration of the coating in any respect.

"Previous to the experiments above set forth, I also made some with coal-tar pitch and mixtures of Trinidad asphalt with coal-tar pitch, having been led thereto by the manifest deterioration of such coatings on pipe exposed to the air. The great difficulty was to obtain a coating which should be hard, adhesive and still ductive or elastic. A coating mixture which was satisfactory when used in cold weather would become soft and run or flow when exposed to the sun in spring or summer; and, conversely, a mixture which would be adhesive and fairly hard in summer, would become extremely brittle and fly off from the metal in large areas in cold weather. In many cases, too, no proper adhesion to the metal could be secured, so that by hammering the surface lightly, even in warm weather, considerable scaling off would occur.

"I also tried a mixture formed by adding some linseed oil to coal-tar pitch and asphalt, but here, again, lack of adhesion occurred unless the quantity of oil became so large as to render the material sticky when cold. In all these experiments the aim was to secure a coating which would be a liquid when highly heated, and reasonably hard when cold, so as to obtain the result by dipping or immersing the object in the usual manner.

"I also made some experiments by adding quicklime and resin in varying proportions to the above-named materials, but without satisfactory results.

"The above is written mainly from memory, especially with reference to the last-named set of experiments, which were made at intervals during a period of eight or 10 years prior to 1893, and the record of which is lost or destroyed."

A. P. Boller, M. Am. Soc. C. E.—There is probably no branch of the arts that has received less intelligent scientific study than that of paint, largely due, probably, to its having been left so much to the shop and contractor. With them economy is absolutely the ruling consideration, and left to themselves, the cheapest mixture obtainable is Mr. Boller.

Mr. Boller. chosen. Consequently, the aim of the paint manufacturers is to meet the market, and innumerable compounds have been devised to cheapen mixtures.

There will never be any great improvement in paints until engineers and architects take the matter absolutely into their own hands and hold strictly, not only to a specification of quality, but also to the condition of the metal to which it is applied. No matter how good a paint is, it cannot be efficacious unless the metal is in proper condition to receive it. This is a most difficult matter to control, as the shop work is completed, when ready for painting, and the anxiety of the shop to get the work shipped under press of erection requirements or to reach an estimate, leads to a most careless application of the paint. The work is usually painted out of doors, which is not so bad in dry summer weather, but in damp weather or frosty weather no paint can get a proper contact with the iron.

The priming coat is the vital coat, and no reasonable expense should be spared to have the metal perfectly dry, and cleaned as far as practicable from mill scale. Poor success with red lead has weaned the writer from a predilection he once had for that paint. He had to have some girders, after less than a six-months' painting with red lead, scraped and reprimed with other paint. The red lead paint had behaved very badly, the rust having thrown it off in great flakes. He is uncertain as to the condition of the girders when they were primed at the shop. Inasmuch as red lead is often adulterated, he had it carefully analyzed, and it was reported commercially pure and the boiled oil was of the best. Further, red lead beside being expensive, taking about 17 lbs. to the gallon, is the worst kind of paint to get applied. It must be made in very small quantities and kept continually stirred, or it will at once settle and cake. It is almost impossible to put it on without streaking; it is not fluid, will not run into cracks, and will be a thin reddish oil in places, and in others thick and pasty. It is all very well to say that is not the right way to apply it, but the yard men and boys at the shop are crowded to get through, and it adds greatly to inspection expenses to have a specially detailed inspector to stand over it. The author's deductions for the use of boiled oil as a primer are a *non sequitur* from his records, and how he can recommend this in the face of his own comments it is difficult to see. He says :

"Linseed oil, so far as known, is the best liquid within reasonable cost that can be used for paints, and is, in fact, the preserving agent of the paint. It is, however, readily destroyed by weather, and to preserve it a pigment is mixed with it. * * * C. B. Dudley, M. Am. Soc. C. E., found that while linseed oil alone, after being dried, absorbed water rapidly, this absorption decreased the greater the amount of iron oxide present, and practically ceased finally."

If oil-primed metal could be immediately covered with a pigment coating, good results might perhaps follow, but between priming and

such coating the time is entirely too great ; the oil is almost immedi- Mr. Boller.
ately attacked by its great enemy, moisture, and destructive oxidation of the oil commences. The extent of rust pitting is only measured by the interval between the coats. When a coat of oil is put on it will run more or less and skin over in places where it collects. This part will not dry hard and will produce a gummy substance which will ruffle up when paint is applied, or when painted over will leave a place under the skin which will remain soft, leading to the pitting mentioned as follows by the author : "Under the scale, more particularly on the eye-bars and heavy angles, it was not uncommon to find oil in almost a liquid condition. The outside of the drum was pitted more or less and showed rust under the paint, although this was generally soaked full of oil." Now, if this condition prevails on a structure erected less than a year, wherein has the oil been of advantage ?

The author's record shows up much better for the oxide of iron paint as a primer than pure oil, and he demonstrates absolutely the necessity of a pigment for best results. The key to all painting, of course, is to prevent oxidation, and that paint is the best and cheapest which prevents moisture attacking the oil conveyor for the longest time. To accomplish this result, cheap ingredients cannot be used, irrespective of their combining qualities, and they should be combined on a rational basis of experimentation. There are few such paints in the market of which the writer is aware, but there are some that have been intelligently compounded on scientific principles. They are necessarily not cheap paints, but give them a chance on new clean dry metal, and the record will be very different from that listed by the author. If economy in painting is of great importance, let it be exercised upon the finishing coats, but do the priming with the best material attainable. There is not much use in putting expensive paint over cheap priming, for by the time the work is ready for the second coat, rust will have started, and good and bad paint will come off together.

A priming paint has been prepared by Mr. A. H. Taylor, which he manufactures under the name of "Eureka," after several years of careful experiment, which is a combination of certain ingredients with the purest boiled linseed oil treated by a secret process rendering it practically impervious to moisture, which in the writer's opinion is the true direction in which to improve paints. He has seen metal covered with one thin coat of Mr. Taylor's prepared conveyor oil alone, that after four years of continuous exposure to the elements appeared as fresh as the day it was put on, while the adjacent portion purposely left uncoated, was badly rusted and pitted. With pigment added to such a conveyer, as an additional fender against oxygen and to obtain color, such a paint would seem to come very near to an ideal primer.

Mr. Boller. The grinding together of pigment and oil for any paint the writer considers of importance, as the only way to thoroughly commingle the ingredients, although entirely impracticable for red lead compounds. But it should be done with the iron oxide paints if the best results are to be obtained. No paddle mixing can take the place of mechanical grinding.

Mr. Gerber. EMIL GERBER, M. Am. Soc. C. E.—The author's attention has been called to an error in relation to the pigment used by the Chicago and Northwestern Railway. He was informed by the chief engineer of the road that the object of roasting was to drive off sulphur. Mr. Davidson, the chemist and engineer of tests, says, however, that it is to drive off moisture.

The discussion brought out by the paper is exceedingly interesting and much more general than the author had dared to hope. The important point, viz., the necessity of absolutely cleaning the metal, seems to have been generally recognized and all agree with it.

The choice of a pigment is another matter and the difference in opinion is perhaps an honest one. The author has been criticised as being prejudiced in favor of one article, not to put it stronger. He wishes to state, however, that when he began the examination, after having read Mr. M. P. Wood's able papers and others, and knowing the great favor in which red lead was held, he was at least as ready to find good red lead paint as any other and was greatly disappointed when most of that examined proved so unsatisfactory.

Mr. Emery is undoubtedly right in his conclusion that almost any effort to protect metal with paint is of some benefit. The more perfect this effort is, and that in the direction of the manner of application more than in the material, the better will be the result.

Mr. Just calls attention to the fact that rust is in streaks to the height of trucks on the New York Elevated railroads and this shows clearly the necessity of using a tough and adhesive paint. The author noticed similar rust streaks on a bridge on the old Boston and Providence Railroad. The structure spanned a highway and high wagons had evidently rubbed off from the lower flange the red lead which covered the structure well elsewhere, but which was brittle.

It is interesting to compare the covering powers claimed for various paints by different Members. The truth is pretty well brought out by Mr. Sabin and others that the more area a paint covers, the thinner the film is, and hence the less it is able to protect the metal, the question of merely coloring a given surface not being at issue here.

Mr. Montfort and others object to the use of oil as a first coat, because in transportation cinders get into it and the surface is rough forever after. The same objection would hold if good paint were applied just before shipment, and the metal should be cleaned in the field at all events.

Mr. Thomson's suggestion of heating rust to dehydrate it seems to be a good one. Mr. Gerber.

Mr. Robinson has found some things in the paper which are rather curious. How one bridge on which red lead was good out of eight painted with it makes 71% is new mathematics. Perhaps brittle paint that does not adhere well is not objectionable to him. The rails out of the old foundation on the site of the Woman's Temple in Chicago were seen by the author. He believes, however, that the condition was quite as much due to their being incased in cement concrete as anything else, for some iron taken out of the masonry of another building which had stood 20 years was just as clean, but showed no sign of any paint.

Mr. Nichols draws some conclusions with which the author does not agree. That metal in one bridge may be smoother than in another is not strange when a little thought is given to the subject. If for one the metal lies out of doors for some time before being manufactured and gets rusty, while for another it is kept under cover and worked up as fast as received, the difference is produced at once, even if both lots were equally smooth at first. If paint did not prevent a thin film of rust from spreading there would be few structures in existence that could be said to be evenly fairly protected a year after painting. Mr. Nichols evidently infers that the author believes that plates are always less effected than shapes. While he has often found this to be the case and does believe that the chances are in favor of plates, he would by no means wish to convey the idea that it could not well be otherwise, and in the case of at least one structure it is distinctly so mentioned.

That "rust is unknown under red lead paint" is true only for those who have not looked for it carefully. A circular recently issued by a paint manufacturer gives a lithograph of a very bad case of it. A case similar to the one illustrated was found by the author recently at Providence, R. I., on some metal which had been painted with red lead within six months. The paint was intact, but numerous and large rust spots under the paint were plainly indicated by the discoloration of the paint, and on scraping there was no question whatever as to there being rust under paint. Some go so far as to say red lead causes this rust. The author, however, does not hold such a view in regard to lead paints any more than iron paints.

There seems to be a common idea that oxide of iron used for paint pigments and rust are identical. Such is very seldom the case and the difference is pointed out by several members in this discussion. Rust is hydrated oxide of iron, and the pigments are generally anhydrous oxides. It is no more difficult to get good dry anhydrous iron oxide and mix it with pure oil under proper supervision than any other pure paint, and the author does not recommend getting it in any

Mr. Gerber. other way. There are good mixed paints of many kinds, but most mixed paints on the market are bad as well as cheap. One trouble with paints used on railroads is that the purchasing agents usually award the contract for furnishing paint to the lowest bidder.

Mr. Greiner does not believe red lead to be good on iron structures exposed to fumes of combustion, and it is to be regretted that he has not said so and given his reasons for so doing when he is so much in favor of it in other places.

The author fails to follow Mr. Boller in his deductions from the paper. The author does believe paint to be the best primer under ideal conditions, but thinks his recommendation to use linseed oil under existing conditions is perfectly logical.

The author has been particularly interested in Prof. Sabin's discussion, as he believes, with Prof. Dudley and others, that in the direction of carbons or mixtures with carbons a better paint will be found than in either iron oxides or lead compounds. Unfortunately the right kind of a carbon paint is not yet in common use. Furthermore, he believes that rapid drying paints will give way to the slower driers, as there is no doubt that rapid drying is one of the chief causes of brittleness and want of adhesion.

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THE SANTA ANA CANAL.—DISCUSSION AND CORRESPONDENCE ON PAPER No. 743.*

By J. J. R. CROES, WILLIAM BARCLAY PARSONS, L. L. TRIBUS, JAMES DUANE, R. C. GEMMELL, FRANKLIN RIFFLE, CHARLES W. GREENE, JAMES D. SCHUYLER, DAVID C. HENNY, L. J. LE CONTE and WILLIAM HAM. HALL.

DISCUSSION.

Mr. Croes. J. J. R. CROES, M. Am. Soc. C. E.—The work done on the preliminary surveys described in the paper seemed to be so full, so exact and so costly that the advisability of so large an expenditure for the sake of saving, possibly, a few dollars in construction might be questioned. Still the difficulties due to the nature of the country were so great that the speaker did not think such a criticism would be a fair one. He was much impressed with the ingenuity and fertility of resource of the engineers in the design and construction of these works, and commended the care taken by them in keeping such an accurate account of the force employed and the cost of construction of so important a work, and then placing it on record.

* "The Santa Ana Canal of the Bear Valley Irrigation Company," by William Ham. Hall, M. Am. Soc. C. E., *Transactions*, Vol. XXXIII, p. 61.

Mr. Croes. There is a tendency at the present time, not only in the West, but in all parts of the country, to entrust entirely to contractors the details of preliminary surveys and of construction, the engineer of the company having very little to do with them. In this case the company's engineer seems to have had everything in his hands and to have done his work thoroughly. This method of procedure the speaker considered unquestionably more likely to ensure results in both design and workmanship which are to the company's interest than the placing of the whole matter in a contractor's hands.

Mr. Parsons. WILLIAM BARCLAY PARSONS, M. Am. Soc. C. E.—Two years ago the speaker was sent to examine the work described in the paper, at which time about a quarter of it was in course of construction; he was familiar with the details and could testify to the thoroughness of the work done. A large number of wooden stave pipes under considerable pressure which he had seen were all practically tight. The plaster alluded to in the paper was made of imported Portland cement, which is the cheapest cement, all things considered, that there is in southern California, costing from $3 to $4 a barrel. It is brought there in vessels coming to take cargoes of grain to Liverpool, and the freight charges are nominal. He called attention to the exceedingly rough character of the country in this locality, which had an influence on the cost of the preliminary engineering work. There were no previous surveys whatever, and care was necessary in the adjustment of the details of location to avoid loss of water, which is very scarce in this region. In order also that the work might progress rapidly, it was necessary to make an attack at the same time on different portions, and when the several portions met to have them meet in accordance with the plans. The fact that the work did come out as expected seemed to justify the expense of the original surveys.

Mr. Tribus. L. L. TRIBUS, Assoc. M. Am. Soc. C. E.—The author's method of taking the top water from a silt-bearing and variable stream, and of getting rid of the silt is ingenious. A somewhat similar plan was proposed several years ago for a water-works system where the supply was to be drawn from a river which carried a large quantity of earthy matter. A weir about 100 ft. long was designed to take about 2 ins. of water from the stream. The water was to flow over the weir and then under a suspended apron, rising and passing over another weir. The effect would be to take the clearest surface water over the weir in a

thin sheet, almost stopping the current, and giving the silt a chance to settle. By delivering the water into the bottom of the second compartment, a reasonably clear water was obtained in the upper part, which flowed over the second weir into a receiving basin. The speaker believed that the experimental plant on this system had proved successful so far as the removal of sediment was concerned. Mr. Tribus.

JAMES DUANE, M. Am. Soc. C. E.—It would be interesting to know the amount of leakage where the pipe line is under pressure, and whether or not this leakage is large where the pressure is heavy. The speaker also desired information as to whether the ½-in. bead on one edge of each stave was a success. He questioned if a joint thus made, where the material was not perfectly homogeneous, would be as satisfactory as the ordinary radial form, and asked if a joint in which a bead or tongue on one edge of each stave engaged with a corresponding groove on the adjoining stave would answer better. Mr. Duane.

CORRESPONDENCE.

R. C. GEMMELL, Assoc. M. Am. Soc. C. E.—The writer desired to ask the author the following questions concerning the wooden pipe: 1. Should the lumber used for staves be entirely free from knots? 2. Is Oregon yellow fir good material for staves, and how does it compare with redwood? 3. Should the wood be dry and thoroughly seasoned before being milled? 4. Should the staves be coated on the outside with asphaltum, and, if so, how should the coating be applied? 5. In making butt joints, is it considered better practice to use metallic tongues than wooden splines, and how should the saddles be placed with reference to these joints? 6. Should the bands be cinched up very tightly at first or only moderately so, being left for subsequent tightening when the water has been turned on and the wood given time to swell? 7. What is the maximum distance apart that bands may safely be spaced when the pipe is to be under a very low head? 8. What is the maximum pressure under which wooden pipe may be used with safety? 9. What is the probable life of properly constructed wooden pipe under ordinary conditions? Mr. Gemmell.

Mr. Riffle. FRANKLIN RIFFLE, M. Am. Soc. C. E.—The author is to be commended for his systematic efforts to arrive at the exact cost of the several classes of work performed by day labor, but the utility of his carefully compiled results is questionable, owing to the peculiar financial situation, as elaborated in the paper. If the author had gone a step farther and separated the cost of work done on a cash basis from that which was done when the company was known to be in financial straits, a comparison could be made which would be both interesting and instructive. In addition to this it would also be possible to form a tolerably correct opinion as to what proportion of the increased cost of the work was due to its performance by day labor instead of by contract, a phase of the question which the author has apparently ignored. That the entire work could have been completed at a less cost to the company by an experienced and responsible contractor, goes almost without saying.

Some years ago, while connected with railroad construction on the Pacific Coast, the writer took the pains to compare the cost of "company" work with the cost of contract work, and was somewhat surprised to discover that in every case investigated the former exceeded the latter, the excess ranging from 25 to 100 per cent. During recent years, however, the Pacific Coast railroads have adopted the contract system in their construction departments.

The recently constructed water system of Portland, Ore., furnishes an instructive example to the engineer who may be ambitious to save the contractor's profit for his employer. While the greater portion of the work was performed by contract, there was considerable work done by day labor, under the mistaken idea that this method would ensure more satisfactory results. It is a significant fact that in the former case the work cost considerably less than the estimate of the chief engineer, while in the latter case the cost has already largely exceeded the estimate, and the work is still in an unfinished condition.

Exception must be taken to the author's criticism of the management for "having started in to pay cash for everything." The most satisfactory and economical method of performing work is unquestionably on a cash basis. The payment of the men on the fifth day of each month for work done during the preceding month, and the payment of merchant bills on the tenth day of every month, are certainly in accordance with sound business methods, and should not be con-

strued as an indication of "shortsighted business management." Mr. Riffle.
The grievous mistake made by the management was in beginning active construction before the necessary funds had been secured. This is a mistake that occurs altogether too frequently on the Pacific Coast, and it must be confessed that the preliminary report and estimate of the engineer are oftentimes responsible for it.

The author evidently laments the fact that the credit system had not been introduced at the outset, since this would have enabled the management to conceal from the laborers the awkward fact that they were working for a bankrupt concern, until the work was practically completed.

It is to be regretted that engineers of unquestionable honesty and integrity of purpose often consider it a duty they owe to their employers to bolster up shaky enterprises by deliberately misrepresenting their financial condition to contractors, laborers and material men. As a case in point the following instance may be mentioned: A municipality not many miles from San Francisco sold bonds to the amount of $175 000 for water-works construction, the amount being based on the engineer's estimate. The several divisions of the work were let to as many different contractors. The contracts all provided that 25% of the estimates should be retained until 40 days after the completion and acceptance of the work. A portion of the work, which largely exceeded the engineer's preliminary estimate, was not finished for six months or more after the completion of the other contracts. During this period the engineer studiously avoided accepting the completed portions of the work under one pretext and another, all more or less plausible, keeping the true reason to himself. He had discovered (what no one else knew) that the unfinished portion of the work was largely exceeding his estimate, and that the only way to keep the contractors in ignorance of the fact that there was not sufficient money in the treasury to pay them in full was to withhold the retained percentage, which, according to the contract, was not technically due until the work was formally accepted by the chief engineer. The result was that through this shrewdness on the part of the engineer the water-works system was successfully completed by the contractors, who were compelled to furnish the municipality with about $25 000 worth of labor and materials for which they were not paid, and may never be paid, since the laws of California are such that contractors

Mr. Riffle. have no redress against either municipalities or officials who may conspire to victimize them. It is to be hoped that when the much-talked-of code of ethics for engineers is finally formulated it will condemn in unmistakable language the reprehensible practice of sacrificing fair dealing to zeal and loyalty.

Mr. Greene. CHARLES W. GREENE, Esq.—The very comprehensive presentation as to the construction of these works leaves little opportunity for one who is not a member of the engineering profession to add anything. The writer desires simply to comment upon the construction narrative. Although the work was in progress when he assumed the presidency and management of the company, the greater portion of it was done under his administration. The author frankly acknowledges the cordial co-operation which was given him by the later management, but the difficulties in the way originated prior to the writer's administration. Could the author have known all the facts as to the embarrassments under which the management was laboring during all those months, he would probably have recognized that his department was not alone involved in the unfortunate conditions. While the company did not go formally into the hands of the receiver until December, 1893, at the time it passed into the writer's hands in the previous January and he became its chief executive officer, combining the two functions of president and manager, the primary causes existed which led to its final disaster. Those conditions he had, personally, no responsibility in creating.

Unfortunately there had been no settled business policy previous to that date, and although an immense sum of money had been provided for the company through his financial agency, there had been but little actual construction to show for it. The work upon this canal itself had been begun a few weeks earlier, and one of the first problems presented to him was whether it should be discontinued or carried forward. It was decided to go forward, believing that confidence could be restored among investors in the enterprise, and because the absolute necessity of the situation compelled this construction prior to a given date. Looking back at it and considering the hindrances one after another, the wonder is that it could have been accomplished at all, and but for the excellent administration of the engineering department, which was from beginning to end of the highest order, it could not have been. Necessarily, he was compelled to withhold, even from the

chief engineer, the extent of the difficulties which surrounded him and which were embarrassing the company's finances. It was one of those cases where a great work once begun could not be abandoned without great loss, and its salvation depended upon carrying it forward courageously to completion without an exposure of its weakness. This is neither the place nor the time to discuss these difficulties in detail, and the events which led to the final disaster. Mr. Greene.

It is the writer's wish and duty to confirm the opinion expressed by the author that under more favorable conditions the work accomplished by him would have been done at a minimum of cost and with a maximum of excellence. Engineers seldom have to meet a greater variety of problems in a construction of such magnitude than were presented in that, and, as the paper will show to the careful reader, there was from the beginning a comprehensive grasp of these problems in detail and entirety. Despite all the obstacles, engineering and financial, there was not more than the ordinary delay which attends such enterprises in the final completion, nor was there excessive cost, except as he has specifically accounted for it. If the saving had been affected for which he planned, it would have been so much less than reasonable cost to the company. When the water was turned into the canal there were no defects to remedy, except of the most trivial character, the skill, judgment and faithfulness of the entire engineering force being entirely proved by the results accomplished.

JAMES D. SCHUYLER, M. Am. Soc. C. E.—The works described in this interesting and elaborate paper are in the front rank among the high-class irrigation works of western America, and are creditable in design and execution, notwithstanding the financial difficulties that impeded their construction. The writer took occasion to visit the works shortly before completion. The stave and binder flume which forms so long a link in the conduit is a novelty that was specially interesting. It seems to be a type of structure that is particularly well adapted to the frequent changes that were necessary from canal or tunnel section to the circular form of pressure pipe, which was the case here, as well as to situations where it is desirable for economic reasons to make the depth as great as, or greater than, the width. In designing a conduit of this character and of the very large capacity of the one in question, which has to traverse a very rough country with slopes often steeper than 45°, the width of the bench on which Mr. Schuyler.

Mr. Schuyler. it is to rest is of importance, in order that the grading may be reduced to the least possible amount. Hence every foot that can be saved in the width of the flume is in the interest of economy of excavation. With ordinary flume construction it would be considered objectionable to give so great a depth on account of the extra bracing required, the length of sills needed, the number of side joints to keep tight and the greater width of bench required. The ordinary flume is made in its simplest form where it can be reduced to a single side-board on each side, 18 to 20 ins. in height, and the writer has found it preferable to keep to that plan, even where the width of flume reached 6 ft., rather than to increase the depth. With the stave and binder, however, it is possible to cinch up the side and bottom boards with a few turns of the wrench, and so the objection to greater depth is largely done away with. The only objection to the flume is its cost, and that may be modified to bring it within accessible limits. The figures of cost given in the paper would be of more value for application elsewhere if the cost per 1 000 ft. B. M. for lumber milled and delivered and the cost per pound and weight per foot of iron-work had been given. However, a flume that costs $2 45 per foot, set up complete on a steep mountain side, cannot be considered as extravagantly expensive when its large capacity is considered and its superior quality kept in view. Many irrigation corporations would have spent less in first cost, perhaps, but much more in maintenance and renewals.

The writer is inclined to disagree with the author as to the advisability of constructing wooden-stave pressure pipes without either burying them in the earth or applying some coating or covering for the protection of the wood. In the present case the steepness of sides of the gorges crossed justified leaving the pipes uncovered, and in fact it would have been exceedingly difficult and next to impossible to bury them, except at great cost, although in the writer's judgment it would have been highly desirable to do so, from the fact that they are now exposed to the danger of destruction from brush fires that periodically sweep up these cañons with terrific force, consuming everything in their path by the intensity of their heat. This is a danger that would be removed by burying the pipe in any location, but as there was no alternative in the present case but to expose the pipe to the weather, some preservative to prevent disintegration by the action of the elements should have been applied. To be sure paint,

coal tar or asphalt would be of no value in such a position of exposure, where the moisture oozing from the staves would prevent adhesion, but common whitewash would have acted admirably as such a preservative, not only of the pipe, but of the trestle as well. Mr. Schuyler.

The writer's experience with lime, thus applied, as a preservative of wood has been that it is superior to paint, lead or oils, and it has good resisting qualities in case of fire. For the exterior of flumes he has found it the best of all applications, asphalt being the best for the interior.

If, however, a wooden stave pipe is to be buried and kept full of water under pressure he is of the opinion that it is best to leave it entirely uncoated, and that the burying of the pipe will, under all ordinary conditions, be found to prolong its life, certainly so far as the preservation of the wood is concerned. Decay in wood is a process that takes place only in the presence of both air and water; exclude either element and decay is arrested indefinitely. The burying of a pipe in any close soil practically excludes the air from contact with its exterior, while the water, saturating the wood from the interior through to the outside, renders it practically rot-proof. The long exposure of a wood pipe to the powerful action of the sun and winds, even though it be saturated inside, is almost certain to bring about a disintegration of the surface if it has no exterior coating. The wood pipe built by the Bear Valley Irrigation Company in 1891, and referred to by the author, is evidence of a perfectly preserved pipe, although exposed to the open air. The writer believes that it was thoroughly coated with coal tar prior to its completion or use. It certainly has that appearance.

In reading the paper, as well as in looking over the work, the query is suggested as to why the wooden stave pipe, so successfully used in crossing three of the main drainage lines, should not have been also used for the crossing of Mill Creek. The stream-bed, consisting of cobbles and boulders, could have been crossed with a pipe with quite as great a degree of safety as the bridge, for it might easily have been buried to a depth as great as the bridge piers now reach, while the entire cost would evidently have been considerably less.

David C. Henny, M. Am. Soc. C. E.—In the part of the paper referring to wooden pressure pipes it is stated as one of the reasons for laying the pipe siphons of the Santa Ana Canal above ground, that the Mr. Henny.

Mr. Henny. wood, with free circulation of air around the pipe, is less liable to decay than if buried under ground. The condition upon which the life of wood in wooden pipe depends is its complete saturation. With the pipe exposed to the effect of wind and sunshine, the stave dries out to a greater or less depth from the outside, as atmospheric influences change and conditions are created not favorable to a long life of the outer portion of the stave. A cover of earth or even gravel over the pipe will check the drying-out process, leave the stave moist from inside to outside, and serve to exclude the oxygen of the air, which, in connection with moisture, is believed to be necessary to cause the wood to decay.

That the wood in the 48-in. stave pipe built by the Bear Valley Irrigation Company six years ago is perfectly sound, outside as well as inside, is not surprising to any one acquainted with the lasting qualities of redwood in more unfavorable circumstances. The upper end of this pipe line is buried, and as it may have been examined by the author it would be interesting to know how the condition of the wood compares with that of the exposed portion. This pipe is painted, where laid above ground, with what appears to be asphaltum, but the coating is now in very poor condition. A cover of paint applied to pipes will have the tendency to resist drying out, if the coat be thick and adheres firmly to the surface of the wood. It may be questioned, however, whether such a coating can be made to stick, even if first applied to the pipe when thoroughly dry, for the water will reach it from the inside and tend to loosen it and drive it off.

As it is generally held that wooden substructures, if sound and placed below the level of the ground-water, will last regardless of the character of the soil, it may be of importance to inquire to what ingredients in soil the author refers as possessing wood-decaying influences, and whether such ingredients have a similar effect on wood continually saturated, as in pipe. In the light of present experience, the writer is inclined to the belief that, so far as the wood is concerned, a covering of earth is to be preferred to exposure to the atmosphere. Liability to exterior injury from accidental or malicious interference and danger of fire and wind to supporting structures also largely operate in favor of burying pipes below the surface.

As regards the steel bands, it is certainly objectionable to put them in contact, even if thoroughly coated, with soil containing alkali, and

as with buried pipe the life of the steel bands may be regarded as the controlling element in the life of the entire pipe, there may be a gain in such cases in leaving the pipe exposed. Mr. Henny.

Metal elbows were deemed objectionable as very materially increasing liability to decay, leakage and failure at the joints. It may be laid down as a general proposition that joints in any kind of pipe are not desirable; yet it is believed that joints between wooden and iron pipe can be made in a thorough and substantial manner, neither jeopardizing the life of the pipe at the points of juncture nor causing trouble from leaks or danger of bursting. Ordinarily, joints of this class are made by providing the end of the iron pipe or elbow, whether made of cast iron or riveted iron, with a strong and straight bell or socket 7 or 8 ins. deep, large enough to leave a space of about ¾ in. between the outside of the wood and the inside of the iron. This space is calked full of oakum as hard as the wood will stand. Joints made in this manner are tight under 200 ft. head. Sometimes only part of the space is calked with oakum, the remainder being filled with lead, but the softness of the wood does not allow the lead to be driven up hard.

It was stated that much of the lumber of the pipe staves used in the Santa Ana Canal siphons was quite wet. The terms "wet" and "dry" in connection with lumber are extremely relative, weight being, perhaps, the best criterion. The butt cuts of a redwood tree usually sink when dumped into water, and hence are called sinkers. The wood grows lighter from the bottom up, the weight of lumber, green from the saw, varying from 3 to 6 lbs. per foot B. M., the average for clear lumber, which all comes from the lower part of the tree, being about 4 lbs. when green, and 2.3 lbs. when bone dry. The weight of the pipe staves averaged 2.51 lbs. per actual foot B. M., which, since they were all cut from clear lumber and a large proportion from butt cuts, indicates a high degree of dryness, resulting from between one and two years' air drying in the comparatively moist and cool climate of the coast of northern California. And yet it was not surprising that the staves shrunk perceptibly after arriving in the hot and dry climate of southern California. All lumber coming from the North will do this unless it has been kiln-dried.

Kiln drying is not looked upon favorably where strength and durability are of importance. Lumbermen claim that it takes the life out of the wood, which, if so, may be due to molecular changes in the fiber

Mr. Henny. of the wood or in the preservative acid it contains. As water is depended upon in the case of pipe to preserve the wood, the latter would be of less importance, but it is certain that kiln drying causes the wood to check more or less badly, according to the temperature of the kiln and the greenness of the lumber, and moreover damages it by forming air spaces in the interior of the wood, sometimes revealed by a slight bulge on the surface, produced by the generation of steam, for which there was no ready escape. For pipe staves, air drying is to be preferred, and it is believed that better pipe can be built with partially dry staves than with staves run from kiln-dried lumber.

The use of partially wet staves does not imply leakage at the time of filling, except where the pipe is exposed, and the shrinkage continues after the release of the initial strain on the bands and is not off-set by a further screwing-up of the nuts.

It must be remembered that redwood is soft, and that by hard cinching the staves are materially compressed. If the pipe be backfilled, even with but a few inches of earth, immediately after the final cinching of the bands, shrinkage almost entirely ceases; what little there is is counterbalanced by the elasticity of the wood endeavoring to expand, and the pipe will stand for an indefinite time without becoming loose.

To illustrate the effective manner in which earth covering protects wooden pipe from drying out, it may be deserving of mention that in January, 1894, a short piece of pipe was cut from a 24-in. redwood pipe line laid in the dry soil of the Capitol Hill section of Denver, Colo., in April, 1885, which had not been used since February, 1890, and was found to be still thoroughly water-soaked.

In milling lumber for pipe staves, proper allowance should be made for probable shrinkage and compression, if the completed pipe is not to show too small a diameter, and the use of an objectionable and troublesome narrow stave is to be avoided. James D. Schuyler, M. Am. Soc. C. E., describes in his paper on "The Water-Works of Denver,"* the construction of a 34-in. redwood pipe, and records a shrinkage in the 20 staves that formed the pipe of as much as 3 ins., or 2.6% of the circumference. Presumably this was the combined effect of shrinkage and compression from cinching.

In the construction of the 9 miles of 24-in. redwood pipe at Butte

* See the *Transactions* of the American Society of Civil Engineers, Vol. XXXI, p. 135.

City, Mont., an average reduction of about 2% was observed, with somewhat drier lumber and climatic conditions very much the same as in the case quoted by Mr. Schuyler; and as near as could be told from careful measurements, about one-half of this, or 1%, was due to compression alone. In 8 of the 9 miles the use of a narrow stave or filter was avoided by milling the staves to a width 2% in excess of what was theoretically required. The same allowance of 1% was made for the compression of the Santa Ana Canal pipe staves, and an allowance of but 0.5% for shrinkage, since the lumber was comparatively dry, as stated above. Thus the full diameter of the pipe was attained after cinching, without the use of an extra filler. Mr. Henny.

Objection may be made to the use of partially wet lumber for pipe staves on the ground that uneven shrinkage after milling destroys to some extent the desired uniformity of cross-section of the stave. As a precautionary measure pipe staves are stacked close, and so far as possible, kept from drying out by protecting them from sun and rain. No serious results, however, need be anticipated from any ordinary unevenness of fit of the butt end of one stave against that of another, such as may be caused by uneven shrinkage, for it is readily taken up by even partial cinching, at least in the case of redwood, its compressibility being in this respect an advantage.

In the design of the 32-ft. truss at the bottom of the Deep Cañon pipe crossing, the load, owing to the resultant thrust consequent upon the curvature of the pipe line, has been neglected, as explained by the author, although it averages at that point 485 lbs. per lineal foot as against 1 173 lbs. for the weight of the pipe and water, the latter having been used as a basis for the proportioning of the truss. The fact that the plates of the truss rods have never been brought to their full bearings indicates that the truss, as such, carries less weight than was intended, and proves the pipe, as a tubular girder 32 ft. long, to have greater stiffness than the truss.

While the pipe may thus act safely in part as a girder for a comparatively short span, it is evident that it cannot be expected to do so for the entire length of the trestle. Absence of anchorage on the side hills precludes the idea of the pipe performing the duty of a cable in a suspension bridge, which would in any event be objectionable, as very serious longitudinal strains would thereby be induced. The resultant thrust for the 250 ft. of pipe on the trestle averages 405 lbs.

Mr. Henny. per lineal foot as against 1 169 lbs. for the weight of water and pipe, and is therefore an item not to be neglected in the design of the trestle. Nor should it be overlooked in the spacing of the sills immediately under the pipe, for although the pipe may be capable of transmitting a load from a weak sill to a stronger one, such transmission can only affect the local distribution of the load. In fact, the very stiffness of the tube demands stronger sills or closer spacing of them than would be necessary for a more pliable top load, as it is evident that its rigidity will not allow it to follow an uneven deflection of the sills or settling of the structure, or permit it to correct any difference in the tightness of wedging up under the pipe. In this connection it may be mentioned that the sills were originally spaced 6 ft. between centers on the trestle, and that their number was afterwards increased by the placing of intermediate sills. It is, of course, understood that the resultant thrust in the case under discussion is nothing but the transmitted weight of water from the hillside portions of the pipe line. Its effect has here been discussed in some detail, simply because it is much greater than the writer at first sight expected with a curve of so large a radius.

The junction bays connecting the pipe with the flume are almost perfect from a hydraulic point of view. From a constructive standpoint, it may, perhaps, be asked why the entrance of the pipe was not entirely dropped below the bottom of the flume, so as to insure its submersion even with the smallest flow of water. It is evident that this would have involved an increased cost, which may not have seemed justifiable.

The U-shaped flume is a departure from ordinary practice, and therefore deserves particular attention. It must be conceded that, as developed by the author, it has numerous and great advantages over the wooden box flume, and that it is excellently adapted to the case. Moreover, results have shown it to be thoroughly watertight, as might have been expected. The author states that it is virtually the lower half of a wooden pipe, laid to grade, and this analogy naturally leads to the question why the staves were dressed to flat sides instead of with rounding or cylindrical surfaces, as is usual with pipe, the cost of working being the same in both cases. It seems to the writer that the better bearing that would thus have been obtained for the steel bands on the wood, and for the entire trough in the yokes, would have been an advantage.

Mr. Henny.

The steel bridge and flume were selected as the best solution for crossing Mill Creek. It appears that on the basis of contract prices, supposing no heavy flow of ground-water were encountered in the deep cross-cut, a wooden pipe laid well below the surface of the creek bed would have resulted in a saving, even if its duplication would have been necessary in the near future.

The writer has raised these points, not because he doubts that the author has had excellent reasons for the manner in which the many difficult problems have been solved, but because he thinks an explanation would be interesting.

Mr. Le Conte.

L. J. Le Conte, M. Am. Soc. C. E.—The author's contribution is instructive and worthy of careful study. There may be good reasons for adopting such high velocities for flow of water, viz., 8.5 to 10 ft. per second for flumes, siphons and tunnels, while the open canal velocities are a little less than 5 ft. per second. But it seems to the writer that waters transporting sand in suspension and coarser material rolling along the bottom of the conduit will undoubtedly scour the lining of the waterway to a serious extent. The plan of construction adopted for combination flumes is very economical, and its capacity for discharge must be excellent. The only feature which seems questionable is its durability. This is a matter which experience will decide. The depressed tunnel idea with a lining composed of concrete and an inside facing of wood, always submerged in water to prevent decay, seems to be economical, all things considered, and admits of wide application. In regard to double siphons used across the deep ravines, as far as the writer is able to judge from the data, they will cost when completed about $18 per linear foot. Excepting Tunnel No. 7, this is the most costly portion of the entire work, and the writer is of the opinion that this may be open to some criticism. In the lowest portions of siphons Nos. 2 and 3, the steel bands are described as being 2½ ins. between centers. This would imply that there was in this portion at least more than enough steel in the bands to make a complete steel pipe of the same diameter.

The great practical advantages of the wooden stave pipe over wrought iron or steel pipe stand out prominently when conduits of large size are subjected to comparatively light pressures. In case of iron and steel it is necessary to put in a large percentage of extra metal over and above pressure requirements in order to prevent the

Mr. Le Conte. pipes from collapsing under their own weight while empty. Hence where pressures are light and the diameter of the pipe large, the stave pipe is certainly much cheaper and more practicable in every way. But when the pressures are high the advantages all shift over to wrought iron and steel pipe, because then the calculated thickness of metal to meet the high pressures is sufficiently great to avoid the danger of collapsing when the pipe is empty. In short, no extra metal is required for stiffening. In all such cases the steel pipe is cheaper and better. The only questionable feature about the banded wooden pipe is its durability, and experience alone can decide it.

The idea of laying the siphons on top of the ground seems to be altogether reasonable in this locality. Of course iron and steel siphons have been laid in the same way many years ago, especially where the nature of the soil corrodes the iron. The section adopted for the open canal seems to be well adapted to meet the great variation in volume of water to be handled during the year.

There are some points in the location which might be criticised. There is no preliminary work which requires greater care and judgment to obtain the greatest economy than the location of an aqueduct in a rough country, broken and rocky. Such was found in this case.

The problem is not only the selection of the simplest line with reference to the quantity of work, but also with due regard to the class of work to be constructed. The most economical location, other things being equal, is generally found to be in light cutting, and therefore the line should be laid out with chief reference to this fact. Siphons should also be reduced to a minimum.

In the matter of lined and unlined work the choice is of paramount importance since the one may be roughly estimated at three times the cost of the other. Consequently it should be the constant study of the engineer in charge to avoid as much as possible the necessity of lining the work.

In regard to the actual cost of the work exceeding the estimates, the writer would say that in this class of work it is absolutely impossible to estimate with exactness, because the quantities to be dealt with are largely unknown and variable. Even with complete maps and carefully made test borings, they can only be ascertained approximately. The grand average cost per mile, $39 900, is remarkably low. The writer would like to know the chief reasons why such great variations in fall per mile and velocities were adopted on this work.

Mr. Hall. WILLIAM HAM. HALL, M. Am. Soc. C. E. Mr. Croes' criticism on the point of possible excessive cost of surveying to save "a few dollars in construction" on the flume line might be unanswerable were it not for the fact that the saving of cost was not the only object in view. A bolder and less painstaking method, it was believed, would have resulted in two faults in construction—the first, excessive and unnecessary timber substructure work, thereby increasing perishable parts at some places, and the second, excessive side cutting, thereby increasing the probability of slides and falling rocks at other places. Even on the point of economy alone, the author believes he could have shown that it paid to be most painstaking in location, and Mr. Croes has himself pointed the reason why, in kindly calling attention to "the difficulties due to the nature of the country." Mr. Parsons, also, has in his remarks indicated another reason why the engineering work may have been, in some respects, excessively expensive; the variety in construction, and the detached workings on the several parts. There are still other reasons which the author has not brought out because of a desire to avoid unpleasant reflection, and to hold the paper and discussion within bounds. It is proper to say, however, that the real and material excess of cost in this branch of the work was not the fault of the engineers.

The question of the amount of leakage of the wooden pipes, brought up by Mr. Duane, is difficult to answer quantitatively. When the pipes had been finally cinched and became fully settled and swelled, there was little or no leakage; they were practically, if not absolutely, tight. At one time, in the course of experience with the Deep Cañon pipe, however, it leaked like a very much decayed and broken sieve. The circumstances were these: Construction on each of the pressure pipes was begun at the lowest point or bottom of the U, and progressed thence up the slopes either way, so as to keep the arms of about equal length at all times. It was desired not to let the pipes remain long after banding without water in them, and to have them loaded when the end joinings were made. As a supply could not be delivered to them in time by way of the conduit itself, they were each gradually filled, as completed, by using a small steam pump taking its supply from the cañon stream underneath. One or two rather bad leaks in the Deep Cañon pipe had wasted much of the water out of it, after the pumping plant was moved to Morton Cañon and before the flow came

Mr. Hall. through the conduit. The fact of the wood having been wetted seemed to make it shrink the more. The author desired to see what the effect would be, so it was purposely not tightly reinched before the water came in. A force of attendants was assembled with all necessary tools, and the stream arrived. To say that the result was interesting is but lamely expressing the fact. It was picturesque, and for a short time, just a little alarming. The water spouted and streamed from almost every seam; but all hands, though soon drenched to the skin, worked with a will, and in about an hour the 1 000 ft. of pipe had almost ceased to leak. An inspection several days afterward showed practically a water-tight pipe, there being a few drips which were stopped by tightening a band or two at each point.

Replying to the questions asked by Mr. Gemmell: (1) Anything like a shattered or loose knot in pipe stave lumber certainly would be detrimental, particularly so if in the edge of the stave. It may be said as expressive of a practical shade of meaning on this point, that pipe stave lumber "should" be free from knots, but that very good pipes may be built of lumber having (some) knots in it. Certainly in specifying for staves of redwood, which can be had free of knots, they should not be in it; but in specifying for some other kinds of lumber, used locally for economy, they may be admitted, if sound, and not in the stave's edge. (2) The author has never constructed or supervised the construction of a pipe of Oregon yellow fir, but he believes it to be a suitable wood for the purpose, under some conditions, though not nearly so good as selected redwood. (3) The wood certainly should be well seasoned before being milled; but it is impractical to specify that it should be "dry and thoroughly seasoned." For instance, it is questionable whether "dry and thoroughly seasoned" lumber, according to the standard of arid southern California, could be had from the humid regions of either the Oregon fir or the redwood mills. (4) The question of coating the staves is spoken of elsewhere in replying to Messrs. Henny and Schuyler. (5) The author prefers metal tongues to wooden splines for closing the butt joints. Driving the staves to place and afterwards cinching the pipe sinks the metal into the abutting and adjacent staves, and insures a tight joint. The author thinks that the wooden spline or tongue will not act to so good a purpose in this. Moreover, he believes that decay will start in joints closed by wooden splines long before it will in those closed by metal tongues.

Mr. Hall.

These are points of opinion, but answer the question as put, so far as the author can do so. (6) The bands should not be cinched, before water is taken in, as tightly as ultimately required. This is a point somewhat indeterminate, to be decided by judgment founded on practice. The author does not here attempt reasoning on it. The engineer to the Excelsior Wooden Pipe Company has recently had a spring strain-indicator made, to test the strain on pipe bands in cinching. A series of experiments with some such device would, doubtless, be most instructive on the point of amount of cinching desirable, both before and after water is taken into a pipe. (7) The maximum distance between bands on pipes of moderate size, under very low pressure, might well be varied somewhat with the thickness of staves, the thicker stave admitting the greater space. The author thinks that the greatest allowable distance would always be found between 12 and 18 ins., however. The question of strength of banding is not raised in this connection. (8) The author cannot see how he can answer Mr. Gemmell's eighth question: "What is the maximum pressure under which wooden pipe may be used with safety?" That will depend on the size of the pipe. Moreover, such pipes may be made "safe" under pressure and conditions such that they would be undesirable on the score of economy, as compared to steel pipes. The metal banding, of course, takes the strain of pressure. Having fixed on the factor of safety for the metal, and having had the bands upset for threading so as to get as much strength in the threaded part as in the plain band, the practical limit of safety would seem to be reached when, to withstand the pressure strains, the bands have to be brought so close together that the screw nuts can no longer be operated. In addition to the water-pressure, imprudent cinching while the staves are dry will bring the swelling strain of the wood excessively against the banding and the limit of safety may from this cause be overstepped before one knows it. The strain indicator, spoken of above, will be specially useful in the study of this question. (9) The probable life of wooden pipe is referred to elsewhere.

The remarks of Messrs. Schuyler and Henny about the wooden pressure pipes of the Santa Ana Canal work are welcomed as of special value. These gentlemen have had wide experience with such construction, and they have made in this discussion some suggestions which the author accepts and others which may well justify difference

Mr. Hall. of opinion on points raised. Mr. Schuyler's suggestion of whitewash for the trestles is good. The trestles would have been whitewashed before now had the author remained in charge of the works after construction, with means at command. That the pipes would have been benefited by this coating, at first, however, the author questions. It can be put on at any time. Will the lime do the steel any good? May it not do harm in the threads of the bands, confessedly the weak point of the tube construction? As there seems to be but little difference of opinion on the vital point, that the life of the pipes will be measured by the life of the bands, the thought occurs that anything put on the bands, as, for instance, a lime paste, which is not preservative of the steel and which will hold moisture on it, may hasten its rusting, and unquestionably will make it more difficult to apply thoroughly any preservative paint whenever necessary to use it. That whitewash for the outside of ordinary flumes is beneficial, the author freely admits. But a steel-banded pipe, under pressure and with water oozing and evaporating from its pores, presents different conditions. The author seriously doubts the efficacy and even the admissibility of whitewash on such pipes. In a less degree, and for similar reasons, he doubts the advisability of whitewashing the flumes of the Santa Ana Canal; though had he continued in charge, had the company not gone into the hands of a receiver, he would have tried this wood perservative on a portion of the fluming. There are other flumes, short pieces of the ordinary wooden box kind, not bound with steel, which are whitewashed in the Bear Valley system of works, and there are several longer box flumes in other works in the immediate neighborhood, thus treated, and, apparently, to advantage.

On the point of comparative life of wood in pipes (1) in the open air, and (2) when buried below air influence in close-packed earth which is free from special wood-destroying agents, and will remain moist, there is really no difference of opinion. The author accepts what Messrs. Schuyler and Henny say on this point as literally correct, but the practical application is quite a different thing. Mr. Schuyler concedes that it would have been impractical to have buried the Santa Ana Canal pipes. Mr. Henny seems to think they might have been buried if metal elbows had been introduced. That a good metal elbow or joint can be made in such a pipe—that is, good as an elbow or good as a joint—is true. But its presence is objectionable (1) as decreasing ca-

pacity, (2) as contributing to early decay in bolt holes and oakum joints, Mr. Hall.
(3) as presenting a point specially liable to rapid abrasion by heavy sands and gravels, (4) as presenting a point liable to catch a drift stick or plank and ultimately cause clogging by accumulating weeds or brush likely to be brought to the flume and thence to the pipe, by small slides or rolling rocks from the mountain side, which would not breach the flume.

As to the broad question of the advisability of burying steel-bound wooden pressure pipes in general, there is more difference of opinion. Messrs. Schuyler and Henny seem to think the cases rare when such pipes should not be buried. The author cannot join in this opinion. Mr. Henny touches the key-note of the author's contention in admitting that "with buried pipe the life of the steel bands may be regarded as the controlling element in the life of the pipe"; and he recognizes the deleterious effect of alkali in soils, on the steel bands. Now, the bands can be cared for and replaced with the pipe above ground; they cannot be, if buried. The question would then seem to be: Will the wooden staves of a pipe which is kept saturated above ground last longer than the steel bands of a pipe kept saturated underground? The author thinks, as a general thing, that they will. And beyond this general proposition lies the danger of sometimes encountering unlooked for and specially unfavorable conditions underground, and not realizing them until too late.

As to the advisability of coating stave pipes when placed above ground. If a coating has been or can be suggested which (1) can be put on after the pipe is ready to receive the water, (2) can be made to stay in good condition and uniformly effective, (3) or can be effectively renewed, (4) will tend to preserve both the wood and the steel, and (5) will not render the pipe much more inflammable and subject to destruction by brush fires, the author will admit that the pipes might be covered with it to advantage, if it would pay to do so. Coal tar put on very hot and thin, so as to be absorbed by the wood, is the only thing which the author knows of that will answer these requirements in some degree. But can it, practically, be thus applied when the lumber is dry enough to take it? It could not have been on the Santa Ana Canal pipes, because the lumber never was dry enough to take a coating. Moreover, if it entered the pores sufficiently to preserve the wood, it would keep the moisture from the outside, and thus (besides

Mr. Hall. being inflammable itself) render the pipes more liable to catch fire from brush fires.

The author cannot understand the philosophy of maintaining a claim of long life for wood pipe, based on the condition of water saturation through the outside, and then wanting to apply some gummy substance into those pores which will prevent the water from thoroughly penetrating them. Mr. Schuyler says: "Saturating the wood from the interior through to the outside renders it practically rot-proof." That is precisely the condition which the author would seek to maintain by not coating with hot coal tar, which, in order to hold on, must penetrate and close the pores. It is because of the creosote in coal tar that it preserves wood. This volatile oil evaporates in a few years from the wood surface, leaving only a gummy substance in the pores. There is no evidence that this gummy substance is a preservative. Railroad structure timbers often rot very quickly after the creosote has been evaporated or washed out from their coal-tar coating. A new coat cannot be made to take hold while the pipe staves are wet, and it may be inconvenient and certainly would be harmful to empty and dry the pipe sufficiently to allow of effective recoating.

Mr. Henny says: "With the pipe exposed to the effect of wind and sunshine, the stave dries out to a greater or less depth from the outside, as atmospheric influences change, and conditions are created not favorable to a long life of the outer portion of the stave." Now, if this be true of uncoated staves, with a hydrostatic pressure behind them supposed to be sufficiently heavy to drive water enough through to moisten and keep moist the surrounding earth, were they buried, is it not equally true of staves coated with coal tar? A coating of coal tar, acting as a cuticle or skin, is far from airtight. The air gets to the wood quite freely after two or three years, at most. Coal tar coatings deteriorate very rapidly when exposed to freely circulating air and sun in southern California. The creosote is soon gone. If the water is prevented from oozing out of the pores within, it is the tar gum soaked far into those pores which stops it. The author thinks this will not conduce to the life of the outside part of the pipe, concerning which Mr. Henny is solicitous if the pipe is not coated. Or if the water is not prevented from oozing through by the gum stopping the pores, then does it not conduce to the early washing away of the preservative creosote? The author thinks it may. And in this

condition may it not thereafter be the water and not the coal tar which will be the preservative ? Mr. Hall.

But why, it may be asked, coat a wooden pipe when buried in earth, if it is not coated when exposed in air ? Simply because the coating, when covered in from the sun and free circulation of air, preserves both the wood surface and steel from harmful soil influences, and stops the pores of the wood, keeping the moisture away from the steel bands. Earth is sufficiently dense and close to preserve the coating, and the coating, under these conditions, preserves the pipe, both wood and steel parts. But earth is frequently not sufficiently airtight or free from alkali to preserve wood wetted from one side only, or to preserve steel kept moist.

The author presents these arguments to promote thought on the part of those who may read them, and to stimulate observation by those having opportunity. They are not advanced dogmatically. Being himself slow to accept the older theories and conclusions which have not as yet been proved by practice, and which may have been arrived at without due reasoning, he cannot expect such experienced practitioners as Messrs. Schuyler and Henny to accept his newer views on this point without first having strongly presented the old case. This they have now done.

That the 2 400 ft. of Santa Ana Canal wooden pipes are exposed to brush fires by not being buried, is true. But so are the 14 000 ft. of flumes. And as a patrol has to be maintained to look out for the flumes, and will have to walk the pipe location in so doing, and as a most effective fight can be made against fire where water is had under pressure, as in a pipe, it does not seem that much additional risk, in the aggregate, is run on this score by having the pipes above ground.

As engineer and manager to the pipe company, Mr. Henny seems to have thought it a criticism that his stave lumber was wet when it was expected to be well seasoned. Criticism was not intended. The idea was to record a fact, which, under the circumstances, could not have been avoided, and to point to the necessity for taking lapse of time and season of year into consideration in drawing specifications for pipe lumber. The discussion on this point brought out from Mr. Henny, however, is a helpful contribution to our knowledge on the subject.

Mr. Henny says : " In the design of the 32-ft. truss at the bottom of the Deep Cañon pipe crossing, the load owing to resultant thrust

Mr. Hall. consequent upon the curvature of the pipe has been neglected, as explained by the author." This statement is not correct. The fact is that, although "the writer believed there was no necessity for giving the trusses additional strength," such strength was planned for. The plan of the work calls for four trusses to support the two pipes, two at the center and one each side of the full-width bents (see Fig. 9, Plate IX).* Only two of these trusses have been built, there being but one pipe as yet to support. As Mr. Henny has proceeded, the author understands, on the supposition that there were to be only three trusses, and as he has misunderstood the wording above quoted, he is in error as to the load-supporting provision made and to be made in the 32-ft. central span. The author believed there was no necessity for the provision, but it was actually planned for and made in the trusses, as far as constructed.

Again, Mr. Henny, admitting that "the pipe may thus act safely in part as a girder for a comparatively short span," the 32-ft. span in question, at the center of the trestle, says, "it is evident that it cannot be expected to do so for the entire length of the trestle." And he concludes that the effect of the thrust-resultant due to the curvature is "an item not to be neglected in the design of the trestle." In this he is, in a measure, right, but he is again mistaken as to the pertinent fact of the Deep Cañon trestle case. He has gone on the assumption that the author's remark about provision in the central span trusses was intended to apply to the design of the entire trestle. In this he is mistaken. The words were: The author "believed there was no necessity for giving the trusses additional strength," etc. Nothing was said in this of the trestle. Moreover, Mr. Henny has assumed that the trestle finished for use with one pipe is complete for the support of the two projected. In this he is also mistaken. The plans for completing the work, when the additional pipe is put on, call for (and have called for, from the time they came under the author's personal supervision, before the work was erected) the introduction of two posts from sill to cap in each bent, in addition to those now in the structure. As Mr. Henny's idea in this connection rests on a wrong assumption, it is unnecessary to combat it. Fig. 9, Plate IX, shows the head of double posting in the center, which as yet built is but single for the one pipe. The fact is that provision has been made sufficient to meet the extra load which theoretically might be placed

* Page 83.

upon the trusses and trestle from the cause Mr. Henny indicates. Mr. Hall.
But the fact remains that the author does not now and never did believe that such load would ever reach the center span trusses in any considerable degree. And, hence, in his original draft of the paper, he referred to this as a "supposed load" which "theoretically would be consequent," etc. That such judgment was correct with respect to the 32-ft. truss part of the work is well stated by Mr. Henny himself as follows: "The fact that the plates of the truss rods have never been brought to their full bearings indicates that the truss carries less weight than was intended." The pipe has taken up the strain produced by the excess of hydrostatic pressure on the outer side of the curved portion, as the author believed it would. But the conclusion next drawn by Mr. Henny on the basis of this fact is not sound. He says "and proves the pipe as a tubular girder, 32 ft. long, to have greater stiffness than the truss." It would only seem to prove the pipe to have greater stiffness than Mr. Henny thought it would have as a girder for the 32 ft. As the truss has not been tested (the pipe holding the strain up from it), how is it possible to say that the fact cited proves the pipe to be stiffer than the truss? The truss has not sagged, it has not been tested.

The author does not contend that no part of the thrust-resultant, to which Mr. Henny alludes, will reach the trestle and thereby increase the load. He wishes to be understood as contending only that the problem is an indeterminate one; that it was unnecessary to make the full provision theoretically demanded; and that the somewhat arbitrary provision actually made was sufficient. In other words, that this was a case in which theory and formulas were not to be depended upon, except to indicate an indefinite danger.

There were two errors recognized by the author as made in the construction of this trestle. One was in setting grades and then afterwards trying to correct 0.1 ft. error by dapping a number of the bolsters or sills (the cross-ties supporting the pipe) to the stringers on which they rested. Each such sill was cut at each end, 0.1 ft. or less on the under side, and a number cracked when the weight came on them. So, to correct this, the total number was afterward doubled, as mentioned by Mr. Henny. Mr. Henny in this connection has made a good point in the following words: "The very great stiffness of the tube demands stronger sills or closer spacing of them than would be

Mr. Hall. necessary for a more pliable top load." If there was error in design in this trestle, it was in not allowing sufficient margin in the dimensioning and spacing of the sills for effect of uneven distribution of the load. The effect was made apparent by the cracking of sills which were dapped as described.

In his reference to the pipe junctions, Mr. Henny overlooks the fact that the plan for the lower bay to each pipe makes provision for gates whose operation would keep the pipes constantly full, thus preventing the result he speaks of as consequent upon the pipes drying out at their upper ends when very little water is running. This idea is referred to on page 95 of the paper, in connection with the wood-lined tunnel, and on page 140, in connection with the wooden junction bay; and it would have been apparent for the other cases had the plan of one of the masonry down-stream bays been appended to the paper. In many such details, the work as constructed is not complete, as the author tried to make clear. Repetition of explanation in the paper had to be brought to an end somewhere.

Replying to a question by Mr. Henny: The staves of the flume were not dressed to a round surface on the outside, because to have done so would have very materially diminished the thickness of their bearing edges, and the author did not think the advantage gained by a snugger bearing for the bands and ribs against the staves, on the outside of the shell, would compensate for the disadvantage of the thinner bearing of the stave edges against each other. He had in mind two facts: (1) that the bands would take neat bearings by sinking somewhat into the wood at the angles made by the stave junctions, and (2) that the flume shell had to act as a box-girder, carrying its load between 8-ft. spaced supports, and that in cinching it tight enough for this duty, $\frac{1}{2}$ in. to $\frac{3}{16}$ in. additional thickness of stave and width of bearing in the shell seams would make a big difference in resistant power.

Replying to the question raised by both Messrs. Schuyler and Henny: The bridge and flume were built for the Mill Creek crossing in preference to laying a pressure pipe for the following reasons: The author does not think it would have been good or safe construction to have laid a wooden pipe across that torrent bed without setting it in concrete and paving it over in a somewhat expensive manner. Such torrents do strange things in dealing with a refilled trench across their

path. A pipe sufficiently large to carry the ultimate volume of 240 second-feet, thus laid, would have cost more than the bridge and flume. A pipe to carry the half-flow, 120 second-feet, thus laid and with the necessary junction structures at the ends, would have cost nearly as much as the bridge and the flume. Subsequent duplication of such a pipe, to carry the other 120 second-feet, would bring the cost to more than the bridge with the flume enlarged to full capacity for the 240 second-feet. The buried pipes could not have been drained without pumping them out or extending a drain pipe from them far down the wash. This latter would have been liable to clogging with silt, and would have made the cost mount up to much more. It would have extended to the land of others. The company did not have right-of-way for it, and could not have secured such right-of-way without a suit for condemnation. The pressure pipes would have acted as sand-boxes at the period of low flow each year, and would have had to be cleaned, after drying them, by hand labor. This labor could be performed well enough if a 6-ft. pipe had been laid for the full capacity flow; but could not be in a 52-in. pipe for the half-capacity. Using either of these sizes, there would have been a material loss of grade elevation by the pipe as compared to the flume, and it was not at disposal to spare. Mr. Hall.

In this connection the author desires to explain a point omitted in the paper, namely, that each of the cañon pressure pipes was intended to have a large blow-off valve in the bottom of its lowest point for the purpose of annual clearance. These valves were designed, made and delivered, but not put in place before the company's failure.

Replying to a question by Mr. Le Conte: The variations in grade slope and consequent velocities were made for the different classes of conduits, principally for reasons of economy. The cañon flume, with 9.71 ft. per second (calculated) ultimate mean velocity, cost over all $4.50 per linear foot. The paved canal, with the corresponding velocity, 4.94 ft. per second, cost $3.75 per foot in length. To have lowered the grades, increased the section and diminished the velocity in the flume would have increased the cost more than could have been saved by increasing the grade, diminishing the section and increasing the velocity in the canal part of the work. This is equally true of a comparison between the pipes and the canal, while as between the tunnels and the canal the difference of cross-section and of velocity might

Mr. Hall. with economy have been made still greater. But the tunnels, flumes, pipes and walled canal, whose calculated velocities all range between 8.36 and 10 ft. per second (not a wide range), closely follow each other, alternating in the line. The water will have no great variations in velocity through this Division I, as shown by these calculations. Moreover, these limits of variation are probably extreme, too low for the walled canal (8.36 ft.) and too high for the tunnel (10.01 ft.). See page 153 of the paper.

Now, equating all of this division, with a probable mean velocity of 9.5 to 9.7 lin. ft. per second, against the canal constituting the bulk of the conduit in Division II, with its corresponding velocity (4.94 ft.), to have equalized the velocities at all would have increased the cost very much. Such comparative estimates were made by the author personally in studying the original general design, and have since been checked in the light of experience on the work.

Mr. Le Conte's suggested reason for keeping down the velocities in the flume, pipes and lined tunnels to avoid scour from transported sands and gravels "rolled along the bottom" may not appear sound when one comes to consider it. Given a load of sand and fine gravel, which, at a mean velocity of 5 ft. per second, would be for the most part carried on or near the bottom of a conduit, thereby wearing its surface away, with a mean velocity of 10 ft. per second, this load will be carried up in the body of the stream and will not wear the channel bottom. The author has known instances of precisely this phenomenon, lined conduits which suffered greater wear at periods of low flow, low velocity and least sand volume than at a period of full flow, high velocity and greatest silt presence. Again, if anyone desires to learn a practical lesson on this point, let him go to a conduit carrying heavy sand-laden waters. Let him remove his clothing and wade in where the current is slowest. There he will feel sands moving on and near the bottom over his feet and around his ankles, wearing the channel lining. Comparatively little sand will be felt against the skin toward mid-depth or higher of the stream. Then let him wade in where the current is swift, stronger than he can stand, where he has to be supported to maintain a footing; he will there feel little or no sand on the bottom, but the skin will be made to tingle by its pelting up and away from the bottom. The effect is striking; the author has frequently tried it.

The lined conduits wear out on the bottom where sand "rolls along." If it did not roll along they would not wear out, for the sides, which are struck by the particles held in suspension as much as the bottom is struck by them, do not wear out. The best solution of such a problem is to clear the water of sand and gravel which cannot be carried in suspension, and then run it so fast that all else is kept suspended and not rolled along. Mr. Hall.

In the Santa Ana Canal case the waters are to be diverted from a stream having velocities, at flood, of fully 10 ft. per second. To prevent such sands as these waters carry and as would be brought into the headworks, over the weirs described, from rolling along the bottom of the conduit and wearing it, the author believes the high velocity of nearly 10 ft. per second in the flumes and pipes is desirable.

Mr. Le Conte's point as to the cost of the double pipe crossings suggests one possible application wherein it might be well taken, namely, in the case of Warm Creek crossing. Here the pressure head, about 60 ft., would have admitted of a single pipe large enough to carry the full 240 second-feet, being put in. With this single pipe, the junctions could have been made from flume to pipe and from pipe to flume again, without any masonry structures, by simply rolling over the flume sides to form the pipe top, at the upper end, and then rolling out the pipe top to form the flume sides again at the lower end. This saving in masonry junction bays, would have gone far toward paying for the larger pipe, and the ultimate saving would have been about $750. But there would have been over $750 more in the work now, and to remain there, with its interest, until required to meet the full demand. Moreover, there are advantages in having the two pipes as against the one.

The Deep and Morton Cañon crossings have pressures too high to admit, in the author's judgment, of introducing one pipe to carry the full flow volume at about the proposed velocities. The distance around each of these cañons on a flume grade would have made the aggregate cost greater than that of the double pipe crossing.

Mr. Le Conte's reference to the amount of steel in the bands at the lower parts of the deeper crossings being sufficient to make an adequate steel pipe suggests this: Preliminary estimates from manufacturers as to cost of steel as well as wooden pipes for the crossings were obtained before choice was made. The wooden pipes were found to be

Mr. Hall. much the cheaper by any adjustment or planning that could be suggested.

The author does not understand Mr. Le Conte's general remarks concerning location studies and relative cost of lined and unlined work, when applied to the subject in hand. There was no possibility of constructing any part of this conduit as an unlined work. This the author tried to make clear in the original article. As a general proposition, however, Mr. Le Conte is right, and his remarks add value to the discussion. It is worthy of note, however, if Mr. Le Conte intended his remarks to imply that, possibly, greater care might profitably have been taken in studying location, Mr. Croes has thought that, possibly, unnecessary expense and care were gone into in this study.

The author notes in Mr. Tuttle's remarks some points of extreme interest on the subject of steel pipes, but does not feel called upon to lengthen the discussion by adding to this branch of it.

It would have been tedious to have "gone a step farther and separated the cost of work done on a cash basis from that which was done when the company was known to be in financial straits," as Mr. Riffle suggests might have been done. There was no work of moment actually completed and measured up while the company was yet on a cash basis. The change was a gradual one, as the article clearly indicates. The suggested corrections for labor inefficiency are believed to afford a key for more detailed analysis of cost. The author would not have felt justified in going further into details and particulars.

"That the entire work could have been completed at a less cost to the company by an experienced and responsible contractor" does not "go almost without saying." This work was a novel one, from start to finish, except in the tunnel driving, pipe construction and canal excavation. These three classes of work were done under contracts by specialists of the very highest standing and with the best facilities. Those portions of the work which were done by the day could not have been contracted at any reasonable cost. The variety of construction was infinite, the pieces many, small and scattered. It would have been next to impossible to have specified beforehand just what was wanted. To have tied the work down to specifications would have sacrificed the value of results, or would have entailed endless bills for extras. The author does not admit that on this class of construction

there are any "experienced and responsible contractors," except in some of the separate specialties mentioned, who could better handle the work than the engineers who were in charge of it. If Mr. Riffle's remarks on this point apply to the unfortunate complications regarding the superintendence of common labor in this case, they are pertinent. Mr. Hall.

Mr. Riffle takes exception to the author's remarks on the cash system of employment for day labor and the absence of time checks, and in so doing he makes much more out of those remarks than was intended, and gives them a meaning they do not convey. The author said, in substance, and still believes, that a better class of men are held on works of this description and better results are had by not paying monthly in cash. The reasons are given in the paper.

Mr. Riffle implies that the author and the management would have been parties to a deliberate deception of the laborers, and he says that western engineers lend themselves to this practice. He has no ground for this stricture. Members are simply invited to read the last two paragraphs of his discussion, and then read the paragraphs of the article which have called them out. The author knows nothing of other examples mentioned by Mr. Riffle, and, hence, has nothing to say of them.

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